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ABSTRACT

During the period 1984-1986, over 30 teachers from the Yorkshire (England) region have worked in collaboration with the Children's Learning in Science Project (CLIS) developing and testing teaching schemes in the areas of energy, particle theory, and plant nutrition. The project is based upon the constructivist approach to teaching. This guide addresses the particulate theory of matter. The document is divided into two main sections, an introduction which gives a background of the topic and describes some of the classroom strategies which may be useful, and the "Scheme in Action," a lesson by lesson account. The "Scheme in Action" is divided into six parts, with each part including: (1) the intentions and underlying theory; (2) the action plan; (3) how to coordinate the activities in the guide; (4) reflections on each part; and (5) practical details and worksheets (where appropriate). (TW)

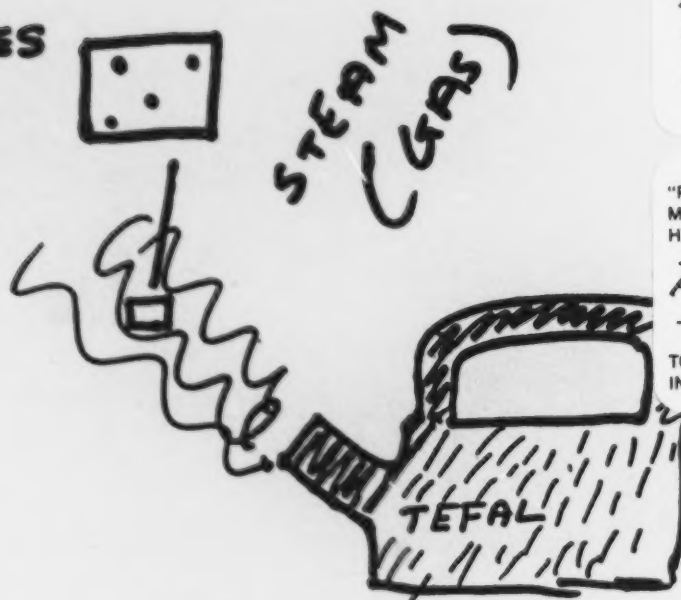
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CHILDREN'S LEARNING IN SCIENCE PROJECT

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APPROACHES TO TEACHING THE PARTICULATE THEORY OF MATTER

S/S
C/R

A research project funded by the Department of Education and Science and undertaken
in collaboration with the Secondary Science Curriculum Review

Centre for Studies in Science and Mathematics Education, The University of Leeds, Leeds LS2 9JT

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● Approaches to Teaching the Particulate Theory of Matter

●
These materials were produced by the Particles Working Group
of the Children's Learning in Science Project

June 1987



Centre for Studies in Science and Mathematics Education
University of Leeds
Leeds LS2 9JT

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The pupil material in this package (the white sheets) may be copied for classroom use.

The Particles Working Group

These teaching materials have been developed and trialled by a group of science teachers working in collaboration with the Children's Learning in Science Project from September 1984 - July 1986. Those involved were:

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Preface

This teaching scheme, which addresses the Particulate Theory of Matter, has been devised by a group of science teachers working in collaboration with the Children's Learning in Science Project.

The scheme is intended for use with pupils aged 13/14 years, of all ability levels, and runs for approximately 10 double lessons. It takes, as its starting point, the intuitive ideas about the nature and behaviour of matter which pupils bring with them to science classes and encourages pupils to construct a particulate view of matter. Opportunities are provided for pupils to make their ideas explicit, to discuss them with others and to develop and modify them. Pupils are also encouraged to reflect on the characteristics of scientific theories and to engage in the activity of theory making for themselves.

The teachers from the Particles working group would advise others not to view this document as the definitive teaching scheme on the particulate theory of matter, but rather as one possible approach. We hope that other teachers will use it as a framework within which they can explore issues and develop teaching strategies which are appropriate to the needs of their own pupils. We would welcome feedback from teachers who use the scheme either as published or in modified form.

The scheme is divided into two main sections; an Introduction which gives the background to the development of the scheme and describes some of the classroom strategies which may be useful, and the Scheme in Action, a lesson by lesson account.

The Scheme in Action is divided into six parts (A-F), each containing the following:

- | | | |
|---|---|-------------|
| 1. Intentions and underlying thinking | } | Green pages |
| 2. Action plan | | |
| 3. The scheme in action | | |
| 4. Reflections on each part |) | Cream pages |
| 5. Practical details and worksheets (where appropriate) |) | White pages |

It is advisable to read the scheme through completely before starting to teach.

INTRODUCTION

1. The place of the particulate theory of matter in the secondary science curriculum

Atoms, molecules, the particulate or kinetic theory of matter have for many years been part of the staple diet of secondary school pupils during their science lessons. Figure 1, or something very similar to it, will have found its way into the exercise books of most pupils before their secondary school career has come to an end. The advent of GCSE has not changed this. A consideration of the National Criteria for Physics, Chemistry, Biology and Science reveals that the particulate theory of matter and its application are still seen as important components of most secondary science courses (e.g. see (1)).

Studies carried out by the Children's Learning in Science Project (2, 3) reveal wide variations in the way in which particulate theory is being taught in secondary schools. Variations may occur in:

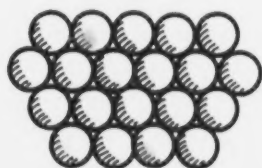
- the age of the pupils when they are first formally introduced to the theory: it may be as early as age 11 or as late as age 15 (i.e. in the first year of a 16+ examination course)
- time spent on the topic: this may be as little as two double lessons or, in one case studied, as much as fourteen double lessons
- the range of practical experiences presented to pupils as evidence for the existence of particles (table 1).

When the Nuffield Sample Scheme in Chemistry was published in 1966 (4) the assertion was made that:

"The idea that matter is made up of particles is now so well known that we can assume that our pupils are familiar with the concept of atoms. Some children have a remarkable knowledge of the atomic theory and the structure of matter by the time they are thirteen years old, but few have really considered the evidence there is to support the theory." (p.219)

Though the Nuffield Schemes were initially intended for the most able secondary school pupils, much material from these schemes can, in one guise or another, be found in most secondary science classes of today.

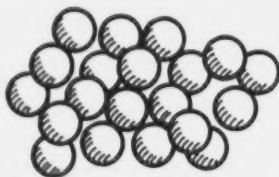
SOLIDS



Particles are:

- closely packed
- in regular arrays
- vibrating about a fixed point
- strongly bonded

LIQUIDS



Particles are:

- closely packed
- arranged irregularly
- moving past each other
- weakly bonded

GASES



Particles are:

- well spaced out
- arranged at random
- moving very rapidly
- not bonded

Figure 1. The Particulate Theory of Matter

TABLE 1. VARIETY OF PRACTICAL ACTIVITIES USED DURING THE TEACHING OF PARTICULATE THEORY

<u>Diffusion</u>	Cooling curves stearic acid/ naphthalene
'Smells' spreading (ether, hydrogen sulphide, ammonia)	
Bromine diffusion into a vacuum	<u>Pressure</u>
Bromine diffusion into air	Volume/pressure changes in a gas
Bromine diffusion in liquid	Temperature/pressure changes in a gas
Porous pot water/air diffusion	Effect of pressure on boiling point of water
Porous pot carbon dioxide/air diffusion	
Camphor diffusion (loss of mass)	<u>Crystals</u>
Ammonia/hydrogen chloride diffusion	Observing crystal shapes
Carbon dioxide diffusion into container/air	Crystal growing
Copper sulphate/potassium manganate (VII) diffusion in water	Hypo crystallisation
	<u>Models</u>
<u>Heat transfer</u>	Nuffield 3D kinetic model simulating states of matter
Conduction in metals	Nuffield 2D kinetic model - marbles (gas model)
Water as a poor conductor	
Melting of metals	<u>Expansion</u>
Cooling curve relating to insulation	Metal expansion/contraction
Convection (potassium manganate (VII))	Liquid expansion
	Gas expansion
<u>Dissolving/Dilution</u>	
Dissolving sodium chloride - 'disappearance'	<u>Others</u>
Dissolving potassium manganate (VII) - colour	Detergent films - adhesion/cohesion
Ethanol + water	Surface tension effects
Dilution experiments	Capillary action - adhesion/cohesion
	Brownian motion - simulation with Nuffield 3D kinetic model
<u>Change of state, heating, cooling</u>	Solids - strength measurements
Change of state ice/water/steam	Density measurements
Evaporation phenomena	

Findings from research undertaken almost two decades later give us less confidence in children's understanding of particulate ideas (5). An analysis of written responses made by pupils to questions requiring the use of particle ideas (questions which were in the National Surveys conducted for the Department of Education and Science by the Assessment of Performance Unit) gave rise to the following conclusions:

At age 15:

- at best, one in ten pupils gave complete arguments based on accepted ideas about particles
- at best, one in five pupils gave partially complete responses based on accepted particle ideas (one in three for pupils studying physics or chemistry)
- alternative particle ideas were used by at least a third of the pupils
- between a quarter and a third of all pupils gave low level macroscopic responses with no mention of particle ideas at all.

Research in the UK and elsewhere also points to the problems that pupils have in understanding particulate ideas (6, 7). This picture of understanding of the particulate theory of matter may be one which classroom teachers recognise as being closer to their own experience. Why is it then that pupils find this such a difficult concept? Are they less able than their counterparts of 1966? This seems unlikely; statistics suggest that at least as many pupils (if not more) are leaving school with examination qualifications as did 15 or 20 years ago (8). Is teaching worse; are textbooks inferior? The notes in pupils' exercise books and the kinds of practical work which are used in teaching particulate theory today have not changed much since Nuffield appeared on the scene; indeed much of what goes on in today's science classes has been heavily influenced by Nuffield.

Rather than laying the blame for the apparent failure of many pupils to understand the particulate nature of matter at the feet of teachers, textbooks, changes in the examination system or the pupils themselves, it may be useful to consider the teaching/learning process itself in a little more detail.

2. How do we learn?

Consider this 14 year old pupil's views on teaching and learning:

"I think the teacher should write on the board or dictate the information into our books. It would stay locked up inside our heads better and we would get more information down as well."

This view reflects some of the experiences of the average secondary school pupil. Several points seem to be implied in this picture of the teaching/learning process:

- initially, knowledge is in the possession of the teacher: THE TEACHER TRANSMITS KNOWLEDGE
- the pupil, in contrast to the teacher is lacking in knowledge: THE PUPIL IS EMPTY-HEADED
- the teacher's job is to pass the knowledge on to the pupil: THE TEACHER IS ACTIVE
- in contrast to the teacher, THE PUPIL IS PASSIVE in simply accepting the knowledge from the teacher.

This rather simplistic view of how learning occurs is sometimes described as a 'transfer view of learning' (9) (as shown in figure 2). Though this view presents a somewhat extreme picture of what occurs in science lessons, it appears that much science teaching may proceed on the assumption that pupils have no prior knowledge of the concepts being taught. Scientific knowledge is often viewed as a collection of 'bits' of truth to be given to pupils. Much time is still spent in writing up notes, copying diagrams and collecting 'facts'.

An alternative way of viewing the learning process might incorporate the following points:

- pupils come to science lessons already holding their own ideas about natural phenomena which they have developed through everyday experiences: PUPILS ARE NOT EMPTY-HEADED

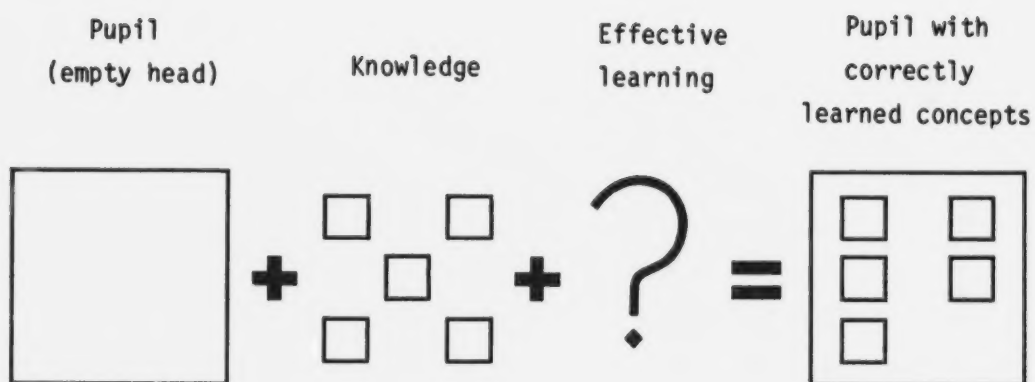


Figure 2. A Transfer View of Learning

- these prior ideas interact with new experiences and phenomena:
PUPILS MAKE LINKS BETWEEN PRIOR IDEAS AND NEW EXPERIENCES
- making links with prior ideas enables the pupil to try to make sense of new experiences: PUPILS MAKE SENSE OF NEW EXPERIENCES BY CONSTRUCTING MEANINGS
- the teacher's role changes. Rather than passing on 'nuggets of truth' to the pupil, he/she works with them, providing experiences which enable them to construct their own meanings: THE TEACHER ACTS AS A FACILITATOR OF LEARNING RATHER THAN A TRANSMITTER OF KNOWLEDGE
- learning is an active process, with each pupil using his/her prior ideas to make sense of new experiences, rather than acting as a passive absorber of information supplied by the teacher: THE LEARNER IS ACTIVE RATHER THAN PASSIVE.

This view of learning, which informs the work of the Children's Learning in Science Project, has been described as a CONSTRUCTIVIST view. A consideration of such a view with reference to the teaching of particulate theory might help to explain some of the problems which pupils encounter. For example, we as teachers may not be aware of the range of alternative ideas about matter which pupils hold, or we may feel that any such alternative views are not firmly held, and can easily be 'untaught'. Perhaps we also fail to recognise that the meanings which pupils construct may not be those which we as teachers expect. An experienced teacher commented recently, when using this teaching scheme for the first time:

"I know that they don't come to lessons with no ideas at all, but I always assume that they know nothing when I start a new topic."

Table 2 illustrates some of the main differences between transfer and constructivist views of learning. (For further reading on a constructivist view of learning and its implications for the classroom and curriculum see references 10 and 11, and the reading list on page 167.)

TABLE 2. COMPARISON OF CONSTRUCTIVIST AND TRANSFER VIEWS OF LEARNING

	Transfer view	Constructivist view
Role of teacher	transmits knowledge	acts as a facilitator, providing experiences which enable pupils to construct meaning
Role of pupil	passively absorbs information	actively constructs meaning
State of mind of pupil	empty or contains easily replaced ideas	contains strongly held ideas based on prior experiences
Learning depends on	the external learning situation; teacher, classroom, books, 'experiments'	the external learning situation <u>and</u> the students' ideas and prior experiences
Learning is	filling empty vessels	modifying or changing existing ideas/concepts
Knowledge is	that which exists 'out there' i.e. independent of the knower	something which has to be constructed by each individual

3. Pupils' ideas about the nature and behaviour of matter

It is not surprising that pupils hold intuitive ideas about the nature and behaviour of matter. These ideas relate to the 'stuff' which is all around them. Certainly pupils bring with them to our lessons their own ideas of solids liquids and gases; of floating and sinking; of evaporating and condensing; of boiling and melting; of heating and cooling - a wide range of phenomena. From exposure to television, books and comics they may also bring with them their own ideas of the nature of atoms and molecules!

Though each individual will have his/her own unique set of ideas about matter, many of these ideas are shared, and indeed are quite common among pupils. This is hardly surprising as they share the same physical and social world, and also share language.

On first examination, pupils seem to hold a bewildering variety of views about the nature and behaviour of matter, some of which might be considered as low level, but very functional. For example:

"The ice melted because I heated it. Heat makes ice melt!"

"Light things float, heavy things sink"

Beyond this, when considering the nature of matter itself, pupils normally view it as a continuum, and even when introduced to the particulate view of matter may reject the idea or limit its use; for example using it only with reference to 'scientific' substances such as crystals and 'chemicals' found in school science laboratories. Many pupils express great reservations about the idea that gases such as air might be particulate.

"But air is just all over you know, it's everywhere. There can't be any gaps in air."

When pupils have already encountered ideas about the particulate theory of matter, whether from experiences at school or in more informal ways (television, magazines, comics for example), they frequently attribute non-scientific behaviour to particles.

The following are among the most commonly held 'alternative' particle ideas, and may be recognised by many teachers as ideas which are often expressed by their pupils.

* Confusion about the nature of particles themselves.

Many pupils have problems in appreciating the shape and size of particles. In some cases there is confusion between particles and biological cells (a confusion which is increased by the use of the word nucleus). The word particle itself can cause confusion, particles of sand for example being seen by pupils as being similar to atoms or molecules.

* Attributing macroscopic properties to particles.

Pupils may use everyday experiences to interpret ways in which particles might behave, often attributing bulk properties such as melting, expanding, contracting, floating and even exploding to them.

* Confusion about the motion of particles.

Commonly held ideas include the following:

- particles only move when they are heated (i.e. they need something to keep them moving)
- particles stop moving at 0° Celsius
- air particles always move upwards.

* Confusion about bonding/forces between particles.

Many pupils have problems in conceptualising bonding, and the way in which it changes from solids to liquids to gases.

* What is in the space between particles?

Pupils may find the idea that a vacuum exists between particles very difficult to accept, particularly when considering liquids and gases. Air is the most commonly mentioned candidate for filling the gaps ("because air is everywhere") closely followed by dust, germs, microbes and other gases.

* Attributing anthropomorphic properties to particles.

Pupils may consider that particles are alive.

4. The development of the scheme

The scheme was developed by a group of 12 secondary and middle school science teachers. During its production the group took the following factors into account:

- the intuitive ideas which pupils have about the nature and behaviour of matter prior to formal teaching
- a constructivist view of learning
- the 'content' of the scheme both in terms of the Particulate Theory of Matter itself and in terms of more general learning experiences to which pupils were exposed
- the group's practical knowledge of what will work in classrooms.

The scheme is designed to:

- elicit pupils' prior ideas about the nature and behaviour of matter
- provide experiences which encourage them to extend, develop and change these ideas, so that they move towards an understanding of the currently accepted scientific view of the nature and behaviour of matter
- provide opportunities for pupils to try out new ideas in both familiar and new settings, and opportunities for them to reflect on the ways in which their ideas have changed.

5. The aims of the scheme

The main aim of the scheme is to introduce pupils to the particulate theory of matter as a theory which is useful in explaining a large number of seemingly unconnected phenomena relating to the nature and behaviour of matter.

Figure 3 shows the main features of the Particulate Theory of Matter which the group felt all pupils should have been exposed to by age 16. It should be emphasised here that this teaching scheme is intended as an introduction to these ideas. The amount of progress made will vary from class to class.

A second aim of the scheme is to introduce pupils to scientific theory making as an activity which they can validly engage in. It is hoped that the scheme will encourage them to view scientific theories as constructions of the human imagination which are open to re-interpretation as scientific knowledge and experience grow.

Thirdly, the scheme aims to help pupils to engage actively in the learning process by providing activities (discussed in the next section) which:

- enable them to put forward their own ideas in a non-threatening environment
- encourage them to respect and value the ideas of others
- encourage them to evaluate ideas (including the accepted scientific ones) rather than passively accepting that there must be 'right answers' which will be presented to them at the end of each lesson.

Finally, it is hoped that throughout the teaching scheme pupils will reflect on their own learning and, with the help of the teacher, become aware of the changes which have occurred in their ideas as the lessons progress. By such reflection it is hoped that pupils will develop an awareness that meaningful learning is an active process which they themselves control rather than the passive activity which was described by the pupil in an earlier section.

As another pupil commented at the end of the teaching scheme:

"I suppose that this course has made me more confident to put forward my ideas. I also feel, subconsciously that I have learned more... We were able to think more for ourselves, we were able to put forward our ideas and each idea was discussed."

Students should:

- a. be confident that ALL substances (not just scientific ones) are made up from atoms.
- b. have some appreciation of the size of atoms.
- c. be able to visualise solids, liquids and gases in terms of the:
 - (i) spatial arrangement of their atoms/molecules
 - (ii) forces resulting in the bonding of their atoms/molecules
 - (iii) motion of the atoms/molecules
 - (iv) temperature effects leading to changes of state.
- d. be prepared to have a go at explaining simple phenomena in particulate terms.

Figure 3. The content of the teaching scheme

6. The scheme in outline

As well as referring to this outline it is recommended that teachers read the full Scheme in Action BEFORE starting to teach it.

Illustrative material (in the form of pupils' written work and comments from both pupil and teacher diaries) has been included in the Scheme in Action. This data has been drawn from many of the teachers and pupils who have participated in initial trials of the scheme, though in places, for clarity of narrative, it has been presented as if it comes from one series of lessons.

It is hoped that the inclusion of this information will enable teachers using the scheme for the first time to anticipate some of the ways in which pupils might respond to the lessons.

a. An outline of each section

PART A: ELICITATION OF PUPIL IDEAS - the means by which the teacher becomes aware of pupil ideas and pupils become aware of their own ideas relating to various properties of matter.

PART B: THE NATURE OF SCIENTIFIC THEORY - the pupils will be actively involved in scientific theory making at a later stage in the scheme. They therefore should be introduced to the nature of scientific theory and theory making.

PART C: A PATTERN OF PROPERTIES - theory making may be based upon spotting patterns of behaviour. In this section pupils consider patterns of properties in the behaviour of solids, liquids and gases.

PART D: THEORY MAKING - the pupils develop their own theories as to the nature of solids, liquids and gases.

PART E: TOWARDS ACCEPTED THEORY - pupil theories are compared and evaluated by the members of the class. The teacher introduces activities which encourage pupils to further evaluate, develop and change their ideas.

PART F: APPLICATION - pupils are given opportunities to try out new ideas about the nature and behaviour of matter, in both familiar and novel situations.

b. Overview

Approximate
timing

2 double
lessons

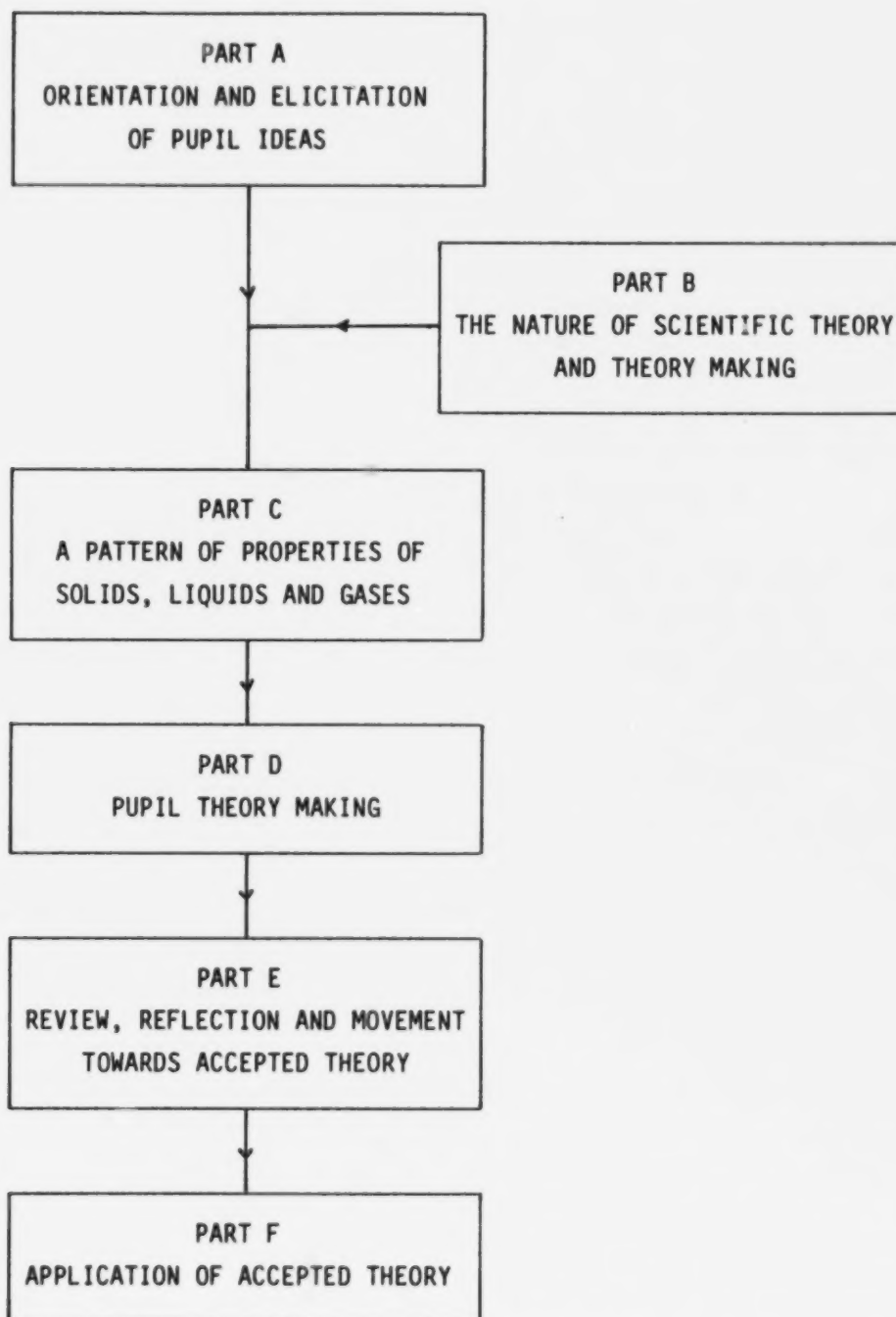
1 double
lesson

2 double
lessons

1 double
lesson

2 double
lessons

2 double
lessons



TOTAL TIMING - 10 DOUBLE LESSONS (70-80 minutes each)

7. In the classroom: some useful strategies

The implications of adopting a constructivist view of learning for the teacher, for classroom practice and for the science curriculum are considered in some detail in separate booklets (10, 11). What is presented here is a brief consideration of three of the main issues which concerned the teacher group as the scheme was being developed: practical work, discussion work and writing.

a. Practical Work

In this teaching scheme practical activities are not of the finding out/testing type often found in secondary science lessons. Instead they are designed to act as 'prompts' to elicit pupils' ideas at various points during the teaching (the other schemes provide examples of practical work which enable pupils to test out their own ideas (Plant Nutrition) and problem solving (Energy)).

In this scheme therefore, practical activities and teacher demonstrations are used to:

- elicit pupils' ideas about various phenomena relating to the nature and behaviour of matter
- encourage discussion and extend pupils' ideas
- challenge pupils' ideas
- allow pupils to apply ideas in both familiar and novel situations at the end of the teaching scheme.

b. Discussion

Discussion is used in this scheme to elicit pupils' ideas, to enable them to share ideas with others, to clarify ideas and to debate new ideas. Discussions may involve small groups of pupils, or the whole class.

(i) Small group discussion

Pupils work in small groups at various points during the teaching scheme, for example:

- in pairs during the initial practical activities
- in fours sharing ideas and developing theories throughout the lessons.

Though science teachers are familiar with handling group work in a practical context, few of us ask pupils to work in discussion groups (sitting, talking about an issue for 20 or 30 minutes) on a regular basis. Many teachers in the CLISP working groups were apprehensive about the use of discussion work when they first started work on this scheme. They developed a series of guidelines which may be helpful to those unfamiliar with group work. These are presented below. The teacher booklet (11) also contains a section on discussion.

- Four seems to be the optimum number for a group.
- Asking pupils to start in pairs then to get into groups of four after a given time is a useful strategy.
- It is usually better to let groups self-select.
- Mixed gender groups selected by the teacher are often doomed to failure for the usual and extensive range of social reasons. If girls and boys choose to work together, be alert to some of the problems which might develop (the main one being boys doing all the talking and girls acting as recorders/scribes).
- Encourage pupils to sit around tables facing each other rather than in lines.
- Make sure that the task set is simple and clearly understood by all pupils.
- Set a time limit.

- Give the task a focus, for example 'at the end of the discussion each group is to produce a poster' or 'a spokesperson from each group is to report to the rest of the class'.

Things to avoid, when organising small group discussions might include:

- standing around in the background if it is obvious that groups feel inhibited by your presence
- asking closed questions
- indicating that a group's or individual's ideas are wrong, or not as valuable as the ideas being put forward by other pupils.

You may wish to consider occasionally audio-taping small group discussions, if you can find a willing group who do not mind being taped. Listening to tapes of discussions can provide the teacher with a great deal of valuable information about pupils' thinking.

(ii) Whole class discussion

Whole class discussion serves various purposes, including enabling pupils to report back from groups, enabling pupils to exchange and clarify ideas, negotiate a consensus view and finally encouraging them to change their views through discussion and debate. In all except the last of these situations the teacher's role should be that of chairperson rather than director of the discussion. As chairperson, it is essential that the teacher avoids the following:

- being judgemental, indicating that some contributions are more valuable or correct than others
- asking closed questions (where the teacher pursues and will accept only one answer)
- interrupting and rephrasing pupils' comments.

Members of the particle working group also found the following points useful to bear in mind when running whole class discussions:

- don't leave the class sitting in their normal places; perhaps arrange chairs in a semi-circle or move pupils to the front of the room
- give pupils time to answer questions. Many teachers wait for only a very short time (2 seconds or less) before moving on to another pupil
- use pupils' names wherever possible
- thank people for their contributions, and indicate that they were valuable by using phrases like 'that was very interesting'
- ask pupils to clarify what they mean, whether they use imprecise language or scientific words (the meaning which a pupil attaches to a word such as force, energy or atom may bear little resemblance to the accepted scientific meaning for the word)
- encourage pupils to debate with each other rather than with you
- encourage pupils to listen when others speak.

(iii) Writing

Writing, like practical work, may serve a variety of purposes within this scheme. There is less of a place for the standard account of a practical (Apparatus, Method, Result, Conclusion) or the exercise book full of dictated notes and neatly copied diagrams. In this teaching scheme, writing is used for the following purposes:

- to record pupils' ideas at various points during the scheme. As it is the nature of the ideas which is important, presentation and length of the work are secondary considerations

- to record group views on posters, which are displayed in the classroom. These posters enable the group to record its consensus views at various points during the teaching scheme and to share these views (through display and reporting back) with others in the class. Again it should be stressed that presentation is secondary though it must be appreciated that many pupils enjoy producing large, attractive looking, brightly coloured posters.

Homework exercises provide a means by which:

- the pupils can be prompted to think further and reflect on some of the issues which have arisen during the lesson
- the teacher (through inspection of written exercises) can gain further information relating to the state of development of individual pupils' ideas.

Some suggestions for written homework are included at the appropriate points in the scheme. (See also the notes on Pupil Diaries below).

If a homework question has been explicitly produced to explore pupils' thinking about a certain phenomenon, then it may not be appropriate to use a formalised marking scheme - complete with ticks, crosses and marks out of ten. For such questions (e.g. 'Jason' Section 1) written comments and margin notes by the teacher would perhaps be better. For example:

"this is very interesting"

or:

"I'm not very clear about what you mean by the gas spreading".

Some teachers asked pupils to make written comments about how they felt the lessons were going. By far the most successful method of collecting data of this kind was to ask pupils to keep a lesson by lesson diary or learning log, in which they recorded what they had done, what they enjoyed (or did not enjoy) about the lesson, issues which interested them or caused them difficulties and so on. The commitment to keeping a diary for the whole 10 lessons encouraged many pupils to take the exercise seriously, and some extracts from their diaries have been included in the account of the teaching scheme which is presented below.

Previous experience of diary work was limited. The following guidelines, which evolved through practice, proved useful:

- it might be useful to set aside 10 minutes at the end of each lesson - a quiet time - for diaries to be written. Alternatively the diaries could be used instead of a formal homework
- respect the confidentiality of each pupil's diary. Do not show a diary to other teachers or read out extracts to the class without the permission of the pupil. Honest, thoughtful diaries will only be written by pupils who trust the teacher concerned
- expect criticisms but if a pupil is genuinely offensive rather than critical don't over-react. A one-to-one discussion with the pupil concerned is probably the best way forward. In our experience diaries are rarely misused
- read the diaries regularly and thoroughly and make positive written comments (not in red ink). It may be advisable not to correct the script unless pupils request this as the purpose of the diaries is to enable pupils to express themselves freely.

For further information on developing written work in science you may wish to contact the National Writing Project (12).

THE SCHEME IN ACTION

PART A:

ORIENTATION AND ELICITATION OF PUPIL IDEAS

1. Intentions and underlying thinking

Part A provides the means by which:

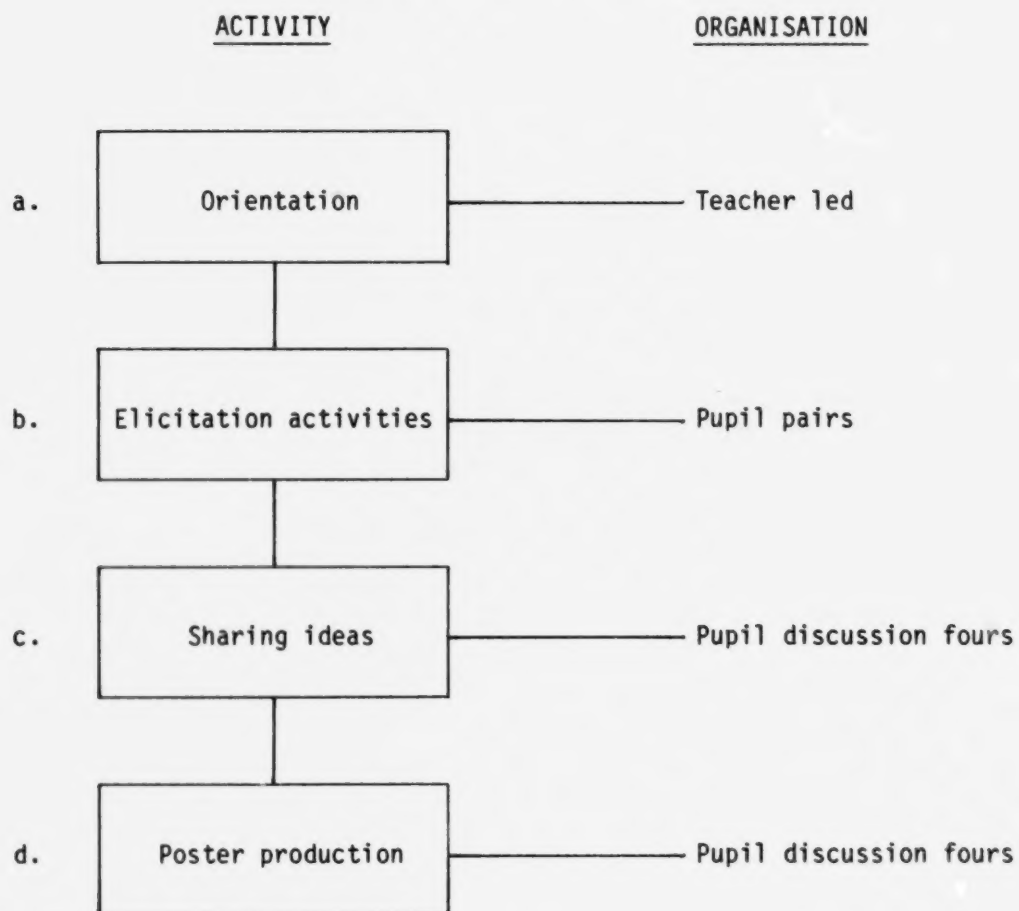
- (i) the teacher becomes aware of existing pupil ideas and
- (ii) pupils become aware of their own and each others' ideas relating to various properties of matter.

For the teacher, elicitation of pupil ideas is important because it gives him/her some insight into the pupil's current thinking. The teacher may become aware of the magnitude of the gap between pupil ideas and the accepted scientific view.

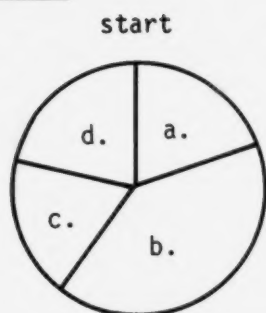
For pupils, the elicitation activities provide an introduction to a classroom/ laboratory in which their thoughts and ideas are sought and valued by other pupils and the teacher. They are encouraged to see that it is valid for them to be involved in thinking their own thoughts and putting forward their own ideas. They are also encouraged to consider the ideas of other pupils, and to realise that these may be of value.

2. Action plan

The classroom activities which make up Part A of the scheme are outlined below and are described in detail in the next Section.



TIMING



- a. = Orientation
- b. = Elicitation activities
- c. = Sharing ideas
- d. = Poster production

Total time for the section -
approximately 2 double lessons
(2 x 80 minutes)

3. The activities

a. Orientation

This sets the scene for the work to come, both in terms of the teaching/learning strategies which are to be used and the focus of the scheme (the nature and behaviour of matter). During orientation the teacher:

- (i) outlines the rather different kinds of demands which are going to be placed upon the pupils - possibly stressing the importance of the pupils actively thinking through the issues which are introduced and then being prepared to state their viewpoint. In this context, the teacher may wish to make quite clear his/her belief that each pupil does possess a fund of existing ideas which can be related to the phenomena under scrutiny and that the first two lessons involve 'getting at' those ideas. (As the lessons progress, the teacher might continue to be quite explicit in making the pupils aware of the 'thinking behind' the various teaching/learning strategies employed.)

The teacher should also explain, right at the start, that the scheme is not a series of isolated lessons but that it provides a framework within which the pupils gradually develop their ideas (no absences for the next 10 lessons!).

It would also be appropriate, at this stage, to give pupils some idea about the demands which will be made on them in terms of written work during the course. The reader is referred to the section on writing which is included within the introduction to the scheme.

- (ii) introduces the context of the work, possibly through teacher demonstrations and class discussion. It would neither be interesting nor productive for the teacher, to describe, at great length, what is to happen during the course. A more appropriate starting point could be a series of lively and thought provoking demonstrations which might make an immediate impact upon the pupils. No doubt individual teachers will have their own ideas but the following have been tried with some success:

Orientation Demonstrations: The stuff which is ALL around us

1. Will it float - will it sink? Blocks of wood, iron, wax in water.
2. Loading a rubber band. What is the maximum load?
How much will it extend by?
3. What load will a hen's egg support?
4. Water/ice/steam - same stuff - such different properties.
5. Making a foam plastic.
6. What load will a paper cylinder take?
7. Blowing the lid off an air filled treacle can - through heating.
8. Hydrogen balloon - up there on the ceiling.

The teacher might present the demonstration in terms such as:

"this is the stuff which is all around us"

"stuff which we take for granted usually"

"why does it behave in this way?"

"what are your ideas?"

Speculation and discussion are encouraged, but at this stage the teacher should remain neutral, accepting all suggestions (however unusual) as being equally valid.

EARLY WARNING: At a later point in the course (movement towards accepted theory - Section 5) the teacher will need to refer to evidence from a liquid diffusion demonstration. It might be a good idea to set up such a demonstration during orientation and to leave it on display over the following weeks - asking pupils to keep an eye on it. Practical details of a suitable demonstration are given on page 48.

b. Elicitation activities

The teacher now directs pupils towards the elicitation activities. As stated earlier, these activities provide the means by which:

- the teacher becomes aware of some existing pupil ideas about the nature and properties of matter
- pupils become aware of their own ideas and those of others in the class.

(i) The activities

Details of some elicitation activities are provided at the end of Part A (white pages). The activities can be related to five separate properties of matter (as shown in table 3 on page 49). These properties are:

- Density (heaviness)
- Strength
- Change of State
- Diffusion (spreading and mixing)
- Compressibility (squashiness)

The listed properties have been selected so that a broad base of experiences will be available to the pupils during the later theory making phase (Part D). Teachers should feel free to add their own activities; the selection in this scheme is by no means exhaustive.

(ii) Organisation

The teacher should select a range of activities covering the five properties. The activities can then be set out in a circus and the pupils tackle them, working in pairs. One way to organise the circus might be as follows:

Class size = 24		
<u>Activity</u>	<u>Property</u>	<u>Number of Sets</u>
Snap	Solid strength	2
Float	Liquid strength	2
Air Freshener	Diffusion	2
Blocks	Density	2
Syringe	Compressibility	2
Melt	Change of State	2
		<u>Total = 12 Sets</u>

For each activity, the pupil pair should be directed to:

1. Read the workcard
2. Carry out the activity as instructed on the card
3. Discuss any observations with their partner
4. Individually complete a copy of the workcard
5. Move on to the next free activity

Time Guideline: activity itself - approximately 3 minutes
discussion and writing - approximately 7 minutes

The activities themselves are trivial in terms of the manipulative demands which they make upon pupils. It should be clearly emphasised to the pupils that the hard work starts after they have made their observations - when they attempt to explain what they have seen. The pupils should be encouraged to think carefully about each activity and to write down their ideas - not what they consider might be the correct answer required by the teacher (N.B: the teacher should make no formal input of information at this stage).

(iii) Pupil responses to elicitation activities

Pupils in the trial schools came up with a wide range of observations and explanations for each of the practical activities, many of their responses being at a very low level. At this stage in the scheme, teachers should not be concerned if pupil responses lack depth, are macroscopic or are purely descriptive, it should be noted, however, that encouraging pupils to think about the phenomena can do no harm.

Given that there were a wide range of responses, and that these responses came from pupils of all ability levels, it was interesting to see that some ideas did occur time and time again, not just within each class, but throughout the 15 classes in which the scheme has been implemented.

A summary of some of the more common responses to four of the activities is presented below on pages 31 to 34. Teachers may find it a useful exercise to monitor the range of ideas which their own pupils put forward in response to the elicitation activities.

It is worth noting that two activities commonly produced responses which referred to particles/molecules/atoms. These were BLOCKS and SYRINGE.

AIR FRESHENER

Observations

- All pupils noticed the smell, and a significant number did not move beyond this descriptive observation.

Explanations

The most common explanations were of the following type:

- It smells more where it's open.
- The smell escapes/gets out when it's open.
- Air carries/draggs the smell out.
- We can smell it because our noses are sensitive to it.

A smaller number of pupils suggested ideas such as:

- Smell is lighter than air so it floats.
- Smell molecules stick to air molecules.
- Smell particles travel through air.

RAZOR BLADE

Observations

- A significant number of pupils expressed surprise that a razor blade should 'float':

"but it's made of metal"

"but it's got a hole in it"

Explanations

Most popular included:

- A skin/film on the water holds up the razor blade.
- It floats if it's put down flat/straight/gently.
- The blade is light.

Less usual, but interesting ideas included:

- Air in the water holding up the blade.
- It's something to do with the relative densities of the blade and water.
- An unspecified type of pressure holds the blade up.

BLOCKS

Observations

- Most pupils made notes about size, shape, length of sides, dimensions.
- Most pupils noticed the difference in density.
- Other observations appeared less relevant. Pupils focused on differences in colour, composition (material of which blocks were made), texture, and the fact that one felt colder than the other!

Explanations

- Many pupils simply reiterated their observations e.g. one is heavier.
- One is heavier due to the materials that they are made of.
- They have different things inside them.
- The heavier one has heavier molecules (atoms, particles).
- The particles in the heavier one are bunched together more.

SYRINGE

Observations

Most pupils noted that:

- Air can be squashed/compressed, sand and water can't be.

Some also observed:

- When you let go of the plunger in the air syringe it comes back up on its own.

Explanations

- Air is compressible/you can squash it.
- You can't squash solids and liquids.
- Air isn't dense but sand and water are.
- Sand is too packed together.
- Sand and water molecules are packed more closely together than air molecules.

(iv) Homework

The elicitation activities are intended to occupy most of the first lesson and part of the second lesson of the scheme. Teachers may wish to set a homework at the end of the first lesson. One possibility would be to set pupils a few open-ended questions (examples H1, H2, H3 can be found on pages 59 to 61). These questions are designed to probe further into pupils' ideas about the nature and behaviour of matter. They should not be formally marked or corrected at this stage. Marking should consist of encouraging comments and questions which ask pupils to clarify or further develop their ideas. It should be made clear to pupils that work will not be marked or graded in the normal way, and that, for the moment, pupils' own ideas are more important than 'right answers'.

An alternative to setting homework is to ask pupils to keep a diary or learning log (see introductory section on writing pages 20 to 22).

c. Sharing ideas

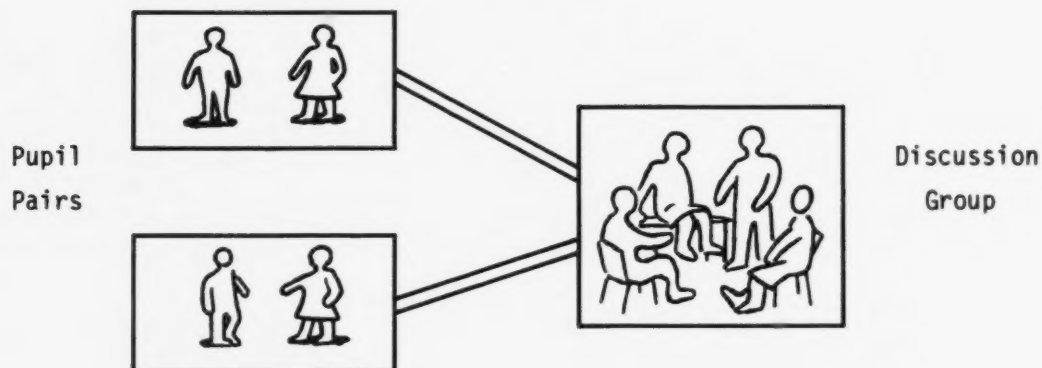
(i) Purpose

The purpose of this activity is to enable pupils to become aware that other members of the class may have different ideas relating to the same elicitation activities. Such an awareness may move the individual pupils to consider/evaluate their own ideas more deeply.

'Sharing Ideas' provides the first opportunity, during the course, for group discussion work. (The reader is referred to the section on small group discussion work which is included within the introduction, pages 17 to 19.)

(ii) Organisation

As pairs of pupils complete the circus of elicitation activities then they are directed to form discussion groups of four members:



Each discussion group is given the responsibility of considering one of the elicitation activities in detail.

Members of the discussion groups might be asked to:

1. Review their own ideas relating to that activity (refer back to personal workcards).
2. Relate their ideas to other members of the group.
3. Discuss the relative merits of the proposed ideas.
4. Reach a consensus over what appears to be the 'best explanation' for that activity.

(iii) Timing

Pupils may need 15 to 20 minutes at the beginning of the second lesson in order to finish the elicitation activities. Sharing ideas and poster production should occupy the rest of this lesson. Pupils often find it helpful if a time limit is put on discussion. Twenty minutes for discussion and twenty minutes for poster production might be an appropriate division of time.

d. Poster production

(i) Purpose

Posters provide a permanent record (a paper memory) of the pupil ideas which exist at the start of the course - prior to any formal input from the teacher. The posters can be referred to as the course proceeds - they provide a baseline against which the development of pupil ideas can be monitored. It may be worth encouraging pupils to reflect on the idea that the posters represent the views of the class at this point in time and, like the ideas of scientists, these views may change.

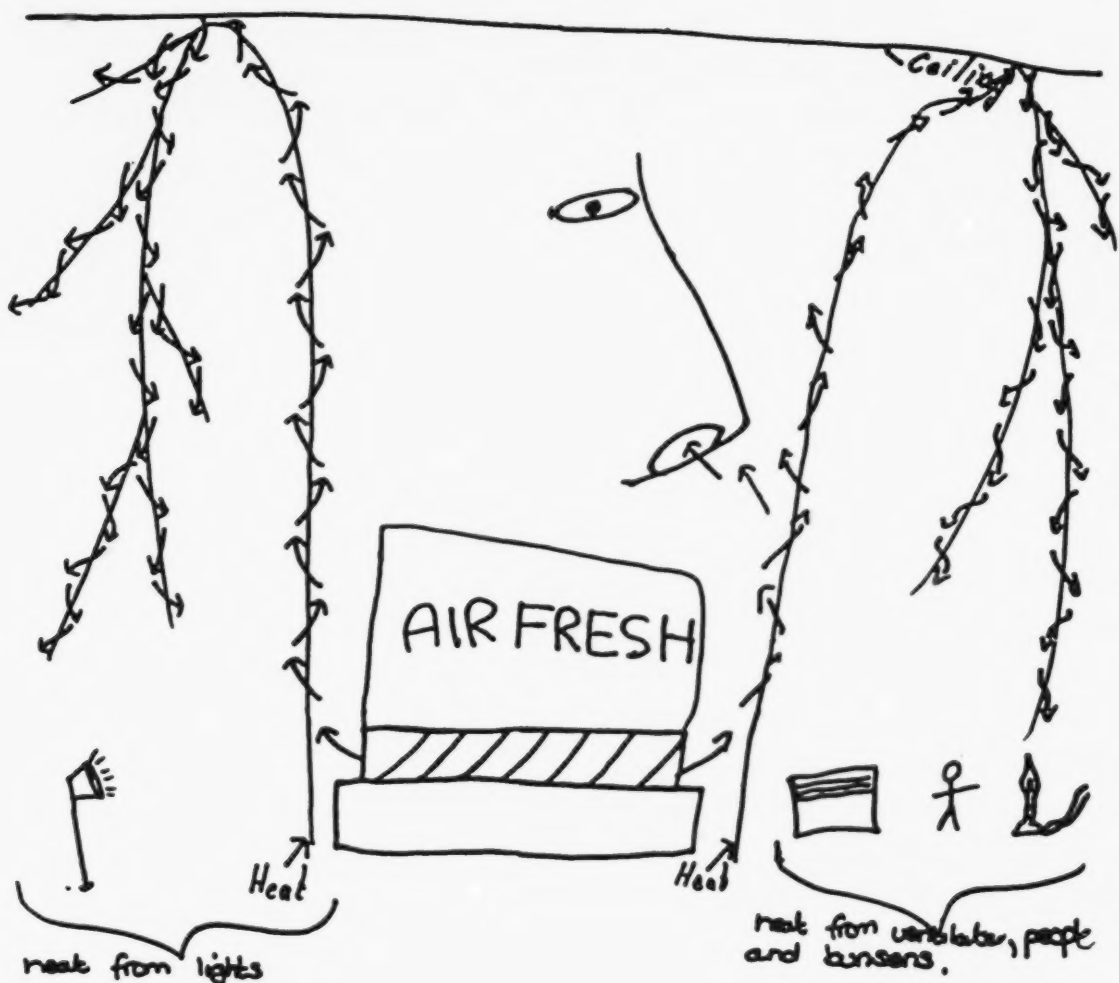
(ii) Organisation

Each discussion group is given a sheet of paper and some large pens and is asked to summarise, on the sheet, the consensus view of the group relating to their particular activity. They may choose to use diagrams as well as words.

When the posters are complete, they are placed up on the classroom wall. Each group could be asked to say a little about their ideas in a report back session if time allows. Teachers may be concerned about displaying ideas which are not scientifically 'correct' around the walls of a classroom or laboratory. One way round this would be to display a 'title' poster e.g. "3C's Ideas on 23 February. Next instalment in 2 weeks' time."

Examples of posters produced by groups are shown on pages 38-41.

Air Freshener



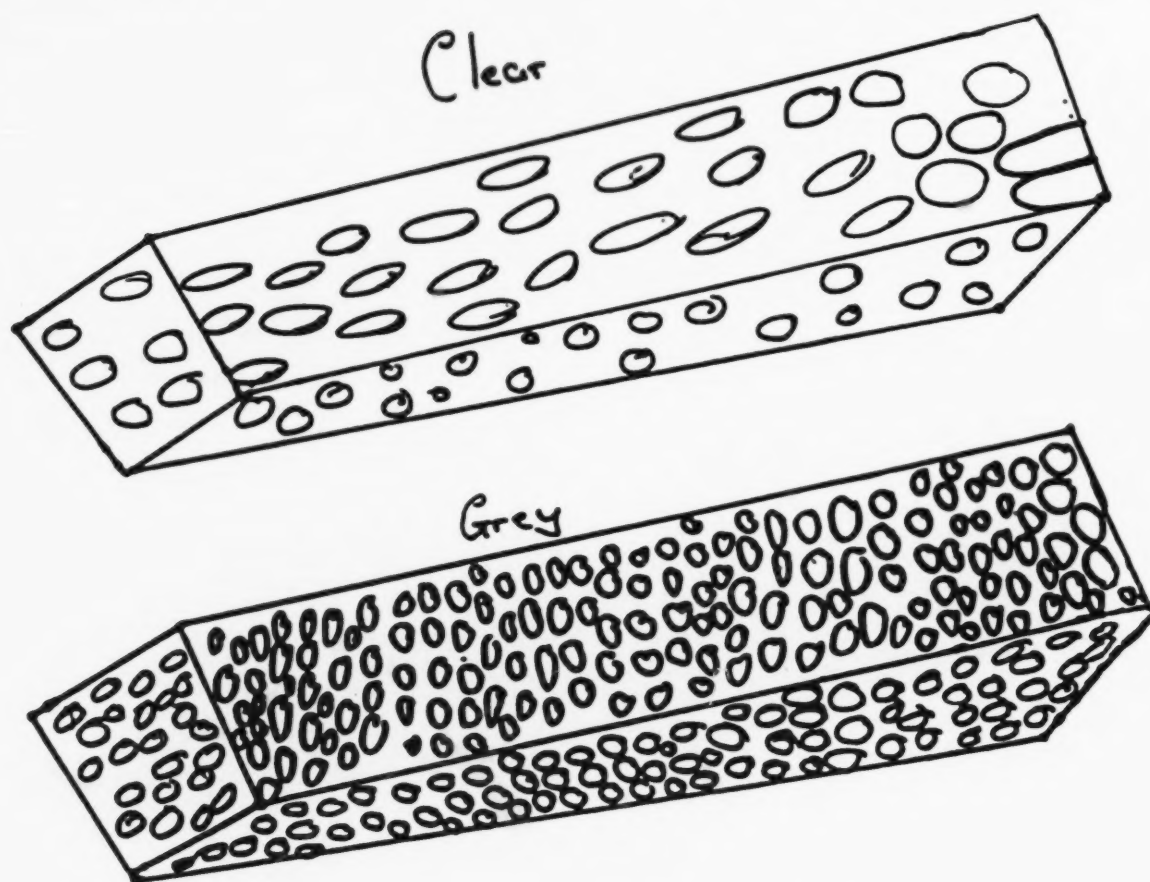
The hot air in the room is rising, when you open the air freshener the smell rises with the air. The smell rises to the top of the room and spreads around the room so you can smell the smell.

Shirley
Amanda

Simon
Robert

Clive
Darren
Darrel

Solids



Particles spaced out in the Clear block
particles bunched together in the Grey block

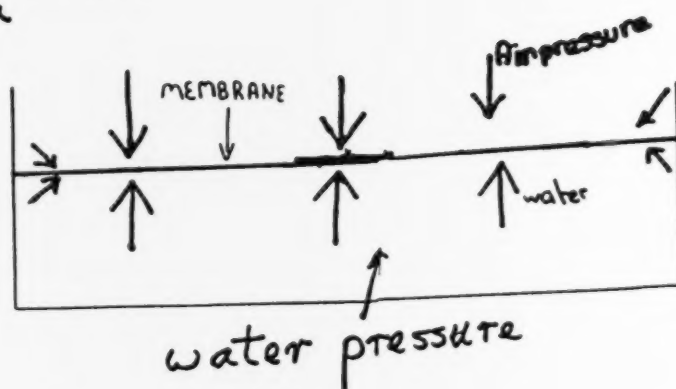
RAZOR BLADE

The razor blade is light and flat and the weight of the blade is spread out over the water's surface.

The water doesn't go through the hole in the middle of the blade because of the skin on the surface of the water. i.e. the MEMBRANE.

The water is like a barricade and the air is holding the blade in place.

skin on surface of water fills the hole in the razor blade



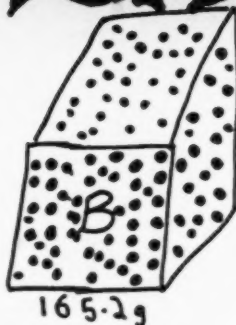
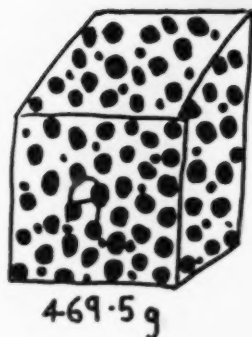
Julie

Sarah

Kirsty

Amanda

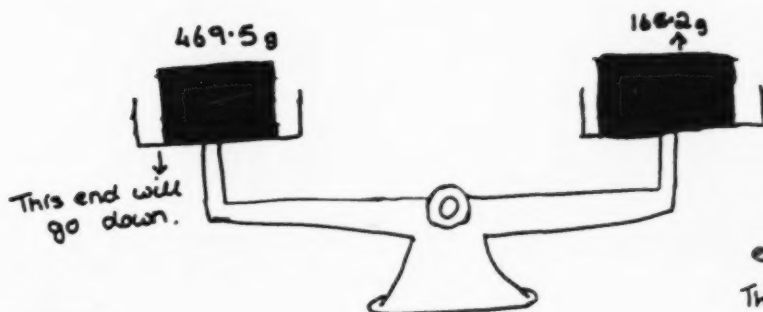
Weights.



- light atoms
- heavy atoms

We got two weights and weighed them both. They were both the same size. We found that A weighed 469.5g. and B weighed 165.2g. Our aim was to find out why B was lighter.

We came to the conclusion that B was lighter because atoms in block A were probably closer together than in B and the second reason is that the atoms are heavier in atomic weight, therefore coming from a different substance. We arrived at that conclusion because it seemed the most logical idea.



Jacqueline
Helen
Peter
Robert
John

* An atom is what everything is made up of. They are the smallest matter that exists and can vary in weight.

4. Reflections on Part A: Elicitation of pupils' ideas

a. General issues

(i) Elicitation activities

Most pupils seemed to enjoy the practical circus. Concerns expressed by some teachers included the following:

- Pupils' written responses on worksheets were very low level e.g. for the air freshener "it smelled because I opened it". After discussion, the working group agreed that perhaps it had been a little naive in its initial expectations about pupils' ideas. If pupils' ideas were low level during the first few lessons so be it.
- Management of the circus of activities.
Teachers from the working group organised the circus in a number of ways; from the one extreme of letting pupils go where they wanted when they wanted to the other extreme of only allowing pupils to move from one activity to another on a signal from the teacher. In terms of the learning environment which the scheme hopes to create, the former option is obviously preferable, as pupils need to be given time to consider their ideas about each activity and may not require an equal amount of time at each one. However, it is recommended that teachers should be flexible and arrange the circus of activities to meet the needs of their own particular pupils.

(ii) Sharing ideas: discussion

- It is sometimes the case, especially if pupils are not familiar with discussion work either in science or in other curriculum areas, that groups may not appear to function well at first. If groups are kept together for the duration of the scheme, however, they do tend to become more cohesive and productive as the lessons progress.

(iii) Posters

- There is a tendency for pupils to get too involved in production matters, often being sidetracked by issues such as how big to make the writing, who should do the writing or which colour of pen to use.

- In mixed groups it has been known for boys to relegate girls to the role of secretary, and then to proceed to dictate what is required, completely ignoring the girls' views. Both girls and boys have a tendency to see the neatness and attractiveness as of paramount importance and the ideas only secondary.
- The teacher can help pupils to overcome these worries by visiting individual groups as they work and encouraging them to use the posters as a way of conveying their ideas to others.

b. Comments from pupils

The following pupil comments come mainly from diaries (which some classes kept throughout the scheme). All pupils quoted are age 13 to 14 - they vary in academic ability.

(i) Reactions to orientation

We did an experiment about loading weights onto an egg. I thought the egg was able to take so much weight, because the weights were put on gradually and not all at once. The egg seemed to get used to one certain weight and then another one was loaded on etc etc. I was suprised that the elastic-band could take as much weight as it did.

"We did an experiment about loading weights onto an egg. I thought the egg was able to take so much weight, because the weights were put on gradually and not all at once. The egg seemed to get used to one certain weight and then another one was loaded on etc etc. I was suprised that the elastic-band could take as much weight as it did."

Stephanie

(ii) Reactions to elicitation activities

Last we did one about two blocks the same size and different weights.

We had to explain why block A weighed more than B. I thought it was something to do with atoms being compressed densely in A and not so packed in B. Pete said something about air trapped in B and so it made the weight lighter.

After this we had to get into fours and decide an experiment to do in more detail.

Me, Pete, H.S and J.W decided to do the weight experiment.

I decided to ^{try} convince Pete about my

idea by saying if you got two bins and put boxes in A and compacting it then putting more in. Then you just put non-compacted boxes in B. I think he agreed but still pressed on with his idea.

After we had to make a poster. I settled to go along with Pete's idea.

I liked the razor blade and the weight experiment but hated the wire experiment.

"Last we did one about two blocks the same size and different weights. We had to explain why block A weighed more than B. I thought it was something to do with atoms being compressed densely in A and not so packed in B. Pete said something about air trapped in B and so it made the weight lighter.

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I decided to try convince Pete about my idea by saying if you get two bins and put boxes in A and compacting it then putting more in. Then you just put non-compacted boxes in B. I think he agreed but still pressed on with his idea.

After we had to make a poster. I settled to go along with Pete's idea. I liked the razor blade and the weight experiment but hated the wire experiment."

Robert (Blocks activity)

We did a few other experiments and then went off into pairs to try our own experiments - I worked with Mandy. First we did the razor blade on the water. We had to get it to float on water - we did.

My idea was that there was a thin film on the water. I had often seen programmes about pond skating spiders, that they skated on a thin film of water. When I mentioned this idea Mandy agreed.

"We did a few other experiments and then went off into pairs to try our own experiments. I worked with Mandy. First we did the razor blade on the water. We had to get it to float on water - we did. My idea was that there was a thin film on the water. I had often seen programmes about pond skating spiders, that they skated on a thin film of water. When I mentioned this idea Mandy agreed."

Shirley (Razor Blade activity)

c. Comments from teachers

These comments are taken from the detailed diaries which teachers kept throughout the sequence of lessons.

(i) On the elicitation activities

".... Students enjoyed doing experiments but inevitably some decided not to follow instructions. Do you notice how many students never seem to read instructions on worksheets personally but become 'experiment-wise' ('method-wise'?) by watching others."

"I have felt greatly stressed by these experimental lessons, probably because of the children continually needing to ask me for advice, matches, ice etc. The lab tech is too busy elsewhere to be to hand."

"It was the first time that they had seen a circus so in spite of instructions not to rush there was a tendency to want to see all the experiments - butterfly style."

(ii) On discussion and sharing ideas

"It occurred to me while giving instructions at the start of the lesson that heavy demands were being placed upon the class:

i.e. make up original THEORIES

take part in MEANINGFUL DISCUSSION

CONCISELY RECORD ideas.

If anybody succeeded in all three it wasn't a bad effort for a first attempt."

"All found starting a poster hard - presentation being all important, content less so. They enjoyed the process once they got going. Gradually got more skilful at getting information down."

(iii) On the teacher's role

"The lesson was successful but I was very busy. It was necessary to keep the class on the boil and moving all the time - may have been impossible if the group had not responded in a positive manner."

"I felt that I was instructing on how to do the experiments too much and wasn't helping the discussion fully ..."

5. Practical details

This section contains the following:

- instructions for a liquid diffusion demonstration (page 48)
- a table of possible elicitation activities (page 49)
- worksheets for the elicitation activities (pages 50-56)
- practical details for the elicitation activities (pages 57-58)
- homework questions (pages 59-61).

* Liquid Diffusion Demonstration

Apparatus needed:

One gas jar $\frac{1}{2}$ to $\frac{3}{4}$ full of water
Copper sulphate solution (saturated)
Rubber tubing and funnel

This copper sulphate solution is carefully run into the bottom of the gas jar through the funnel plus tube. As the copper sulphate solution is more dense than water, it remains at the bottom of the gas jar.

Pupils' attention should be directed towards the interface between the two liquids, and this line might be usefully marked by the teacher, at this time.

(If the teacher has not performed this demonstration before then a practice run would be advisable.)

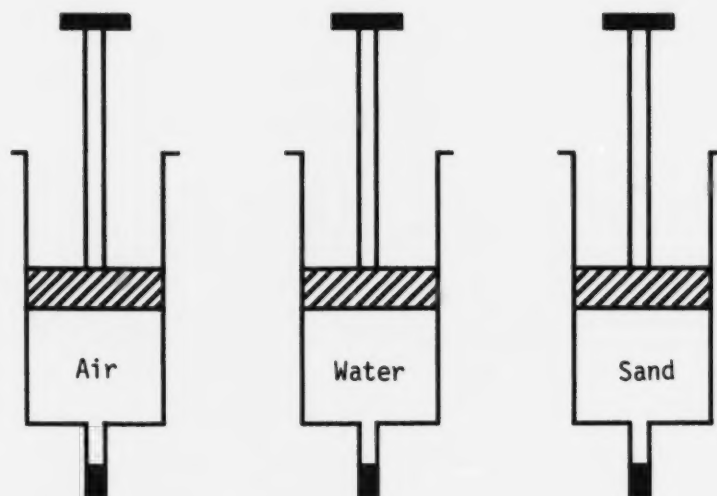
TABLE 3. ELICITATION ACTIVITIES

Activity Property	Syringe E1	Blocks	Blunted Blade E3	Snap	Melt	Water	Air Freshener E7
Density		✓					
Strength			✓	✓			
Change of state					✓	✓	
Diffusion							✓
Compressibility	✓						

This table illustrates which property of matter is considered in each activity.

SYRINGES

E1



Press down the plunger of each syringe.

Write down what you notice.

.....

.....

.....

What are your explanations for what you notice?

Discuss your ideas with your partner before writing down what you think.

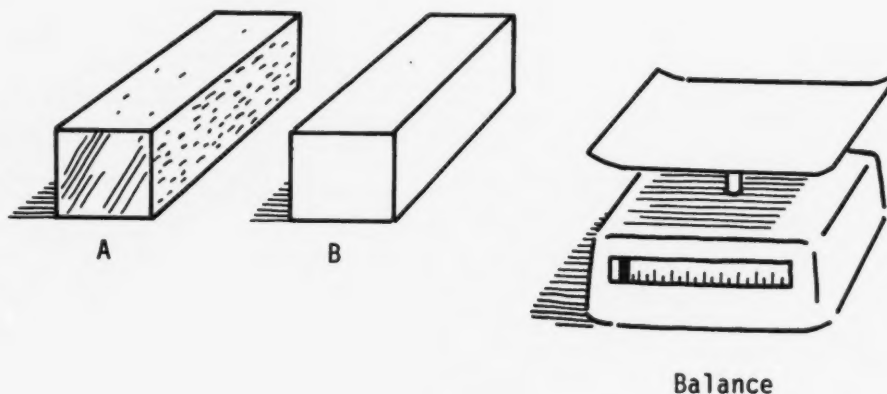
.....

.....

.....

.....

.....



Examine the two blocks.

In what ways are they the same?

.....

.....

In what ways are they different?

.....

.....

What are your explanations for what you notice?

Discuss your ideas with your partner before writing down what you think.

.....

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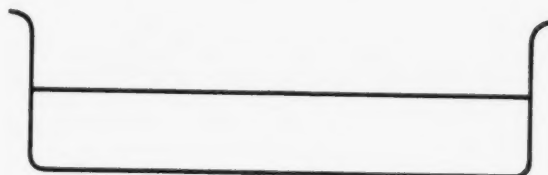
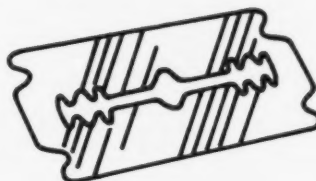
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BLUNTED BLADE

E3



Try to float the blade on the water.

Explain why this is possible. Discuss your ideas with your partner before writing down what you think.

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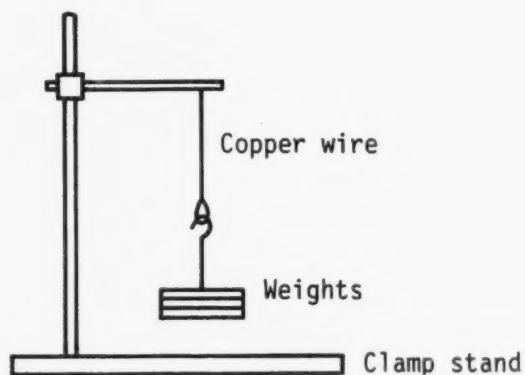
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Add the weights to the copper wire.

What do you notice happening as the weights are added?

.....

.....

.....

What load is needed to break the wire?

.....

What are your explanations for what happened to the wire as it was loaded and then broke. Discuss your ideas with your partner before writing down what you think.

.....

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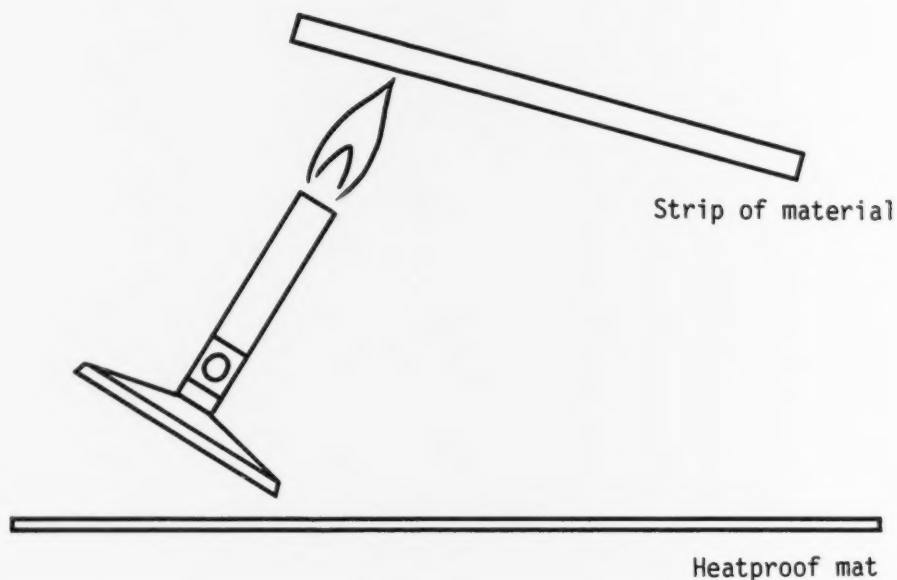
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MELT

E5



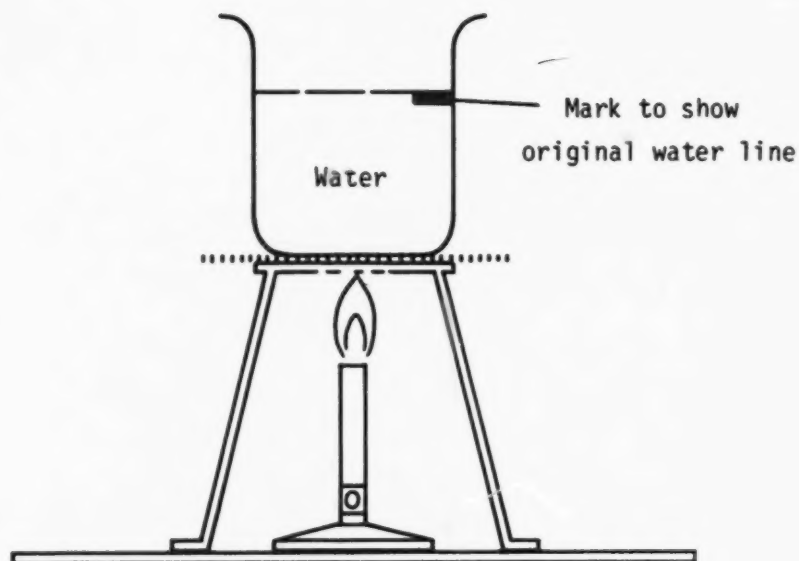
What happens when you heat the strip?

.....
.....

What are your explanations for what you notice?

Discuss your ideas with your partner before writing down what you think.

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Compare the water level with the mark on the beaker - what do you notice?

.....

.....

What are your explanations for what you notice?

Discuss your ideas with your partner before writing down what you think.

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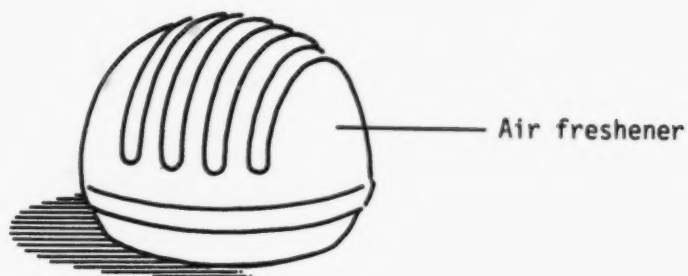
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AIR FRESHENER

E7



What do you notice when the cover of the air freshener is open?

.....
.....

What are your explanations for what you notice?

Discuss your ideas with your partner before writing down what you think.

.....
.....
.....
.....
.....
.....

PLEASE CLOSE THE AIR FRESHENER

Circus of Elicitation Activities

Notes for teachers

E1 Syringes

Requirements:

- 3 plastic syringes (100cm³ capacity or greater)
- araldite or similar
- sand
- water

The 'air' syringe. Depress the plunger so that it is half way down the syringe and then seal the end with araldite or polystyrene cement or by melting it using an electric hotplate.

The 'water' and 'sand' syringes. Half fill each syringe, depressing the plunger so that no air is left in it. Seal the end as above.

E2 Blocks

Requirements:

- blocks from a 'materials' kit - same dimensions but different materials
- a top loading balance
- a perspex ruler

Suitable pairs of blocks might be:

- iron and wood
- lead and perspex
- lead and aluminium

Label the blocks 'A' and 'B'.

E3 Blunted Blade

Requirements:

- very blunt razor blades
- shallow bowls of water (e.g. washing up bowls, grey storage trays)

N.B. If the blades are blunt, pupils should come to no harm. Pupils find 'floating' pins and paper clips much more difficult. A razor blade has added interest because of the hole in it!

E4 Snap

Requirements:

- retort stand and clamp
- lengths of 32swg copper wire (ready prepared with loops at both ends)
- 100g masses

N.B. 32swg copper wire should take a load of 1.5kg.

E5 Melt

Requirements:

- bunsen burner
- heatproof mat
- tongs
- safety goggles
- strips of materials to melt e.g. candle wax, sealing wax, aluminium (use a limited selection)

It is suggested that the teacher tries out melting any materials to be used in advance of the lesson.

E6 Water

Requirements:

- bunsen burner
- heatproof mat
- tripod
- gauze
- 250cm³ pyrex beaker of water
- chinagraph pencil

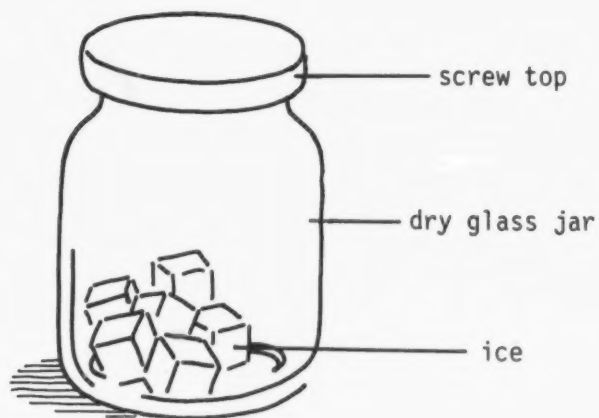
Mark the original level of the water clearly on the side of the beaker with the chinagraph pencil. The bunsen burner should be left at a level which allows the water to boil slowly but steadily throughout the circus of activities. Pupils should not be asked to turn the bunsen burner on and off.

E7 Air Freshener

Requirements:

- domestic air fresheners

If pupils remember to close these after use they are very long lasting.



YOU MIGHT WANT TO TRY THIS YOURSELF AT HOME

Some ice was put into a screw top jar. The outside of the jar was dried with a cloth and it was left for 15 minutes.

Water vapour (condensation) was noticed on the outside of the jar after this time.

Why do you think this has happened?

.....

.....

.....

.....

.....

.....

JASON

H2

Jason's Mum turned the gas tap on a bit in the kitchen but forgot to light the ring. When Jason came home from school he could smell gas as soon as he opened the front door.

Explain, as fully as you can, how the gas smell got to Jason's nose.

.....

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FLASKS

H3

The drawing shows a closed flask containing air.

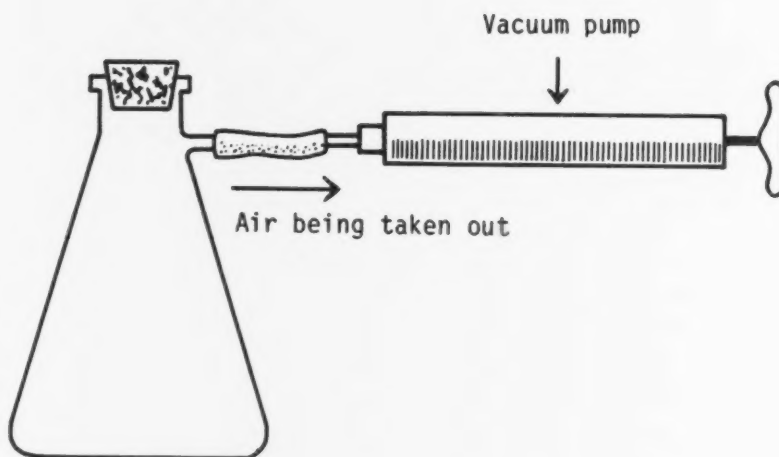
Imagine you could see air in the flask.

Draw in the flask how it would look.

Air



The flask is connected to a pump and some of the air is being taken out.



This is the closed flask after some of the air has been taken out.

Imagine you could see the air in the flask.

Draw in the flask how it would look now.

Air



PART B:

**THE NATURE OF SCIENTIFIC THEORY AND
THEORY MAKING**

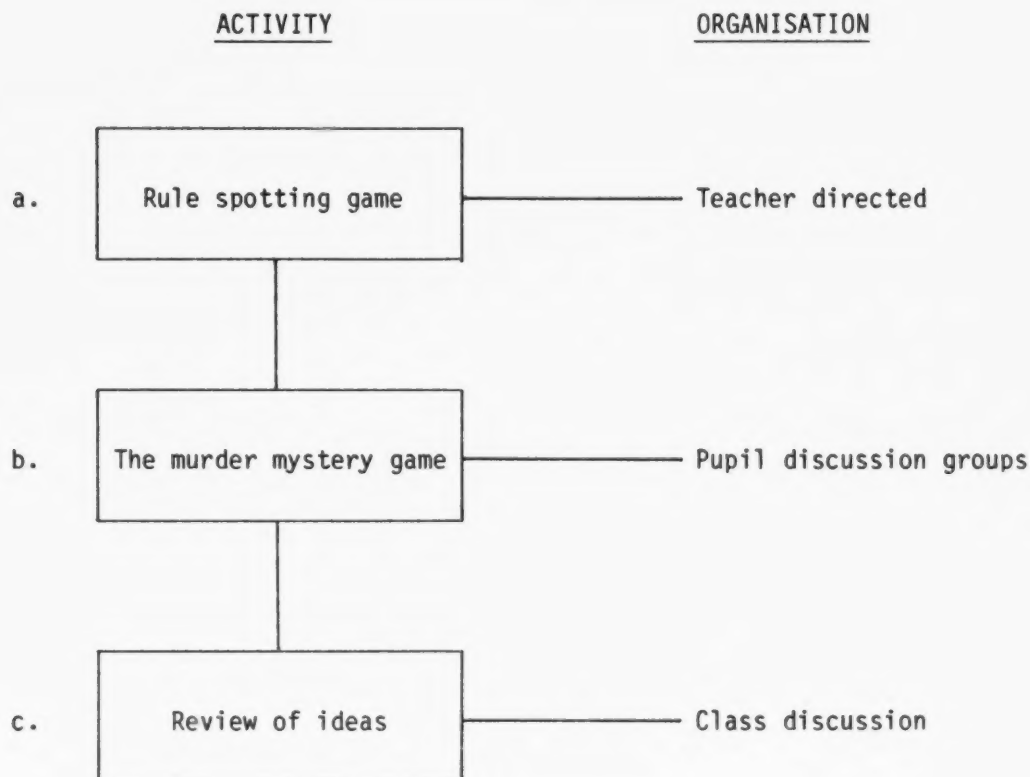
1. Intentions and underlying thinking

Later on in the course the pupils will be involved in developing their own theories relating to the nature of matter. In preparation for this activity it seems both appropriate and necessary to provide the pupils with opportunities to reflect upon:

- a. The nature of scientific theories - 'what they are like'
- b. The ways in which scientific theories are developed.

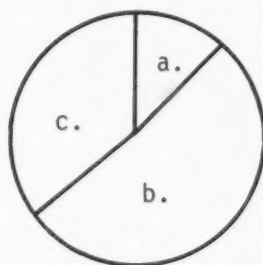
2. Action plan

Part B is divided into a number of activities:



TIMING

start Total time for the section = approximately 1 double lesson
(1 x 80 minutes)



- a. = Rule spotting game
- b. = The murder mystery game
- c. = Review of ideas

The time spent on the games varies considerably from class to class and from group to group within a single class. The rule spotting game might take 10-15 minutes. The minimum time taken to solve the murder mystery has been 10 minutes - other groups have been fully occupied for 40 minutes and not been able to complete the problem.

3. The activities

a. The rule spotting game

This game provides a simple introduction to the session which quickly engages the interest of pupils. It sets up a situation in which data (names) are collected and patterns are looked for within that data.

(i) The game

Without any introduction, the teacher asks any pupil in the class to put up their hand and to state:

"A boy's or girl's name" - "Any name".

As names are offered the teacher writes them on the blackboard putting a tick or cross against each one:

JULIA X

The teacher asks for another name:

ANITA X

And another one:

ALAN ✓

And so on.

The pupils (who are obviously familiar with game playing) quickly recognise what is required of them:

To spot the rule for getting a tick

The rule, which is made up by the teacher, might be:

ANY BOY'S NAME WITH FOUR LETTERS GETS A TICK
--

or any other rule which the teacher cares to devise.

(ii) Organisation

The pupils should be moved to the front of the classroom.

- (iii) On completing the game - the teacher might ask the pupils how they were able to spot the rule. It is likely that they will refer, one way or another to 'looking for patterns' in the names.

The teacher follows this up by suggesting that scientists are often involved in this kind of pattern spotting activity - not only scientists but also detectives which leads into the murder mystery game.

NOTE: The rule spotting game provides a simple introduction to the practice of generating and testing hypotheses. It would not, however, be appropriate at this stage to get involved in a lengthy analysis of the game with the pupils - move straight on to the murder mystery.

b. The murder mystery game

(i) The activity

Each group of pupils is provided with a set of cards. On the cards are printed the clues to a murder. Details of the game can be found on pages 73 to 75. The pupils are asked to solve the murder and bring their solution to the teacher, who has the 'correct' answer.

(ii) Organisation

Pupils are asked to work in their normal discussion groups. There will probably be a time gap between the first and last group completing the exercise. To allow as many groups as possible to gain satisfaction from solving the murder, groups who finish quickly should be asked to reflect on the way in which they reached their solution, in preparation for the review of ideas.

c. Review of ideas

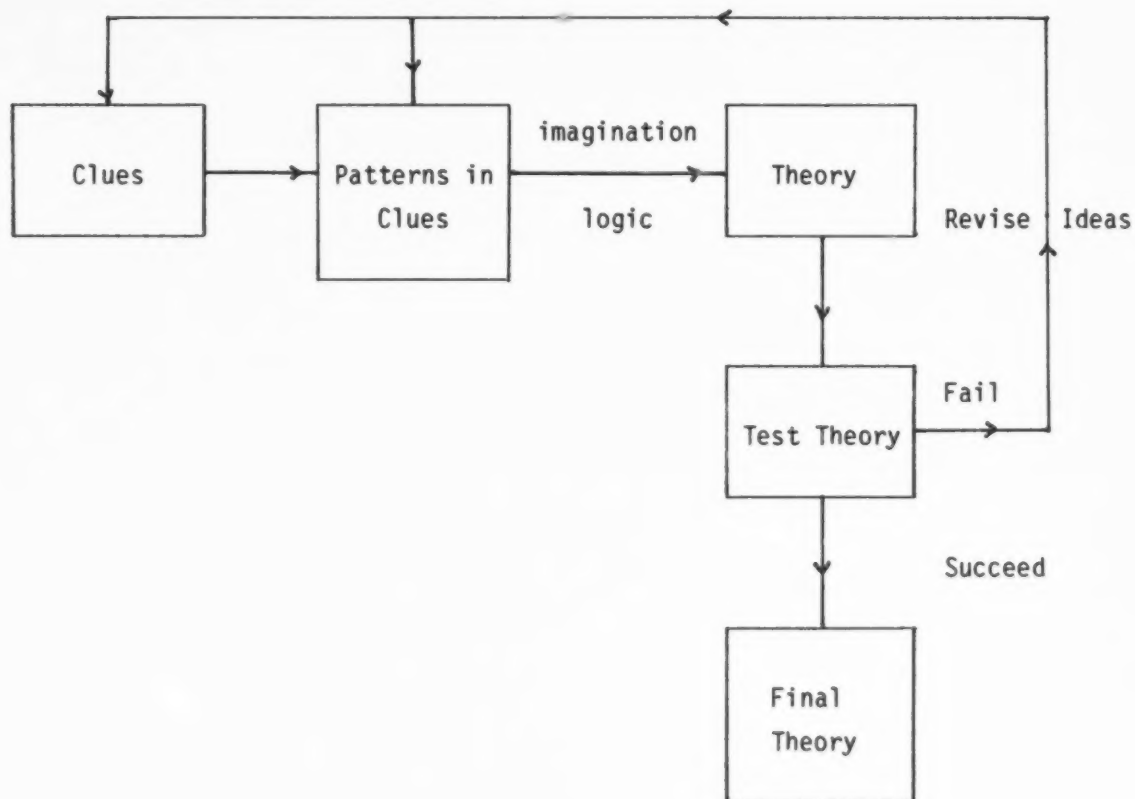
By reviewing the two games and drawing parallels with the world of science, pupils are encouraged to reflect on the nature of scientific theories and the ways in which theories may be developed.

(i) Organisation

This session is organised as a class discussion. Pupils should be invited to sit around the front of the classroom. The teacher will need access to a board or overhead projector.

(ii) The review

In attempting to analyse the steps involved in solving the murder mystery, the following model has proved to be useful as a guiding framework for the teacher. In the first instance, it was set up by a teacher working with a class of pupils.



Consider how the review might develop with a group of pupils.

To start with, the pupils should be asked to think about, and to try to identify, the process by which they solved the murder mystery. The teacher might collect the ideas on the board.

One class began by forming discussion groups and looking for classes in the clues. Thus the clues were sorted into various piles on the basis of names or times or places. When the pupils had picked out classes in the clues, they recognised that they still needed to use their brains in putting together an idea; the idea did not suggest itself directly from the pattern of clues. As ideas were suggested, they were checked out by the pupils. Ideas were abandoned "it can't have been him - he wasn't there" until one was put forward which appeared to work for all of the clues.

The teacher was able to represent these ideas in an outline framework similar to that above, given that:

classes in clues	—————→	patterns in clues
using their brains	—————→	use of imagination/logic
an idea	—————→	a theory
theory checked out	—————→	theory tested

From such an analysis the teacher is now in a position to relate ideas to scientific theory making. Discussion may lead to some of the following ideas:

- scientific theories can 'tidy up' piles of apparently unconnected data
- scientific theory making often involves searching for patterns in data
- scientific theory making may involve making an 'imaginative leap' from data to proposed theory (but need not always be a process that starts with the data)
- scientific theory testing involves checking against all available evidence

- the success of a theory is judged by its ability to interpret or explain all available evidence
- scientific theories are the 'inventions' of people and as such can change with time.

A detailed analysis of all aspects of scientific theory making is not the objective of this session. This is simply an introduction to theory making. The teacher should record any ideas which emerge from discussions so that they can be referred to later on in Part D, Pupil Theory Making.

Note: A number of teachers have expressed doubts over the validity of using the murder mystery analogy as an introduction to scientific theory. The point has been made, quite correctly, that the murder mystery analogy is lacking in that:

the mystery has only one possible, correct solution

the murderer is the person whose name appears on the teacher's answer card. Science, on the other hand, does not deal with unique and everlasting solutions which can be checked against some higher authority. This viewpoint might be introduced by the teacher, as a focus for further discussion. Alternatively, the teacher may wish to modify the game (e.g. by having a blank answer card in a sealed envelope) or to use a different and more open-ended activity.

A possible homework exercise can be found on page 76.

4. Reflections on Part B: The nature of scientific theory and theory making

a. General issues

Both teachers and pupils reacted positively to this section, as illustrated by the diary extracts which follow. Some concerns which arose, however, included:

- some teachers were worried by the rather simplistic view of scientific theories and their generation which is presented in this section
- some pupils were puzzled by these activities and found it difficult to make the link between this lesson and the other more 'normal' science lessons
- other pupils reacted positively and linked the skills required in this section with those required in other areas of the curriculum e.g. Schools Council History
- some problems were encountered in the 'review of ideas'. If the teacher has too rigid a picture in his/her mind of the end-point of this review, it can be difficult to respond positively to pupils own ideas of how they played the games.

b. Comments from pupils

PHYSICAL SCIENCE

Today's lesson was very good we had to find out the murderer of a game with lots of clues we ended up coming up with the answer first it was a very good lesson also very exiting. we grouped the clues into groups like names time and places that that is the best way to work out your theory.

"Physical Science.

Today's lesson was very good we had to find out the murderer of a game with lots of clues we ended up coming up with the answer first it was a very good lesson also very exiting. We grouped the clues into groups like names time and places that that is the best way to work out your theory."

Darren

Luckily we got it all right. After we went to the front to discuss how we got our answer. Pete said we started by eliminating people. I said we started by finding out the clues which were useful and the ones which were not.

Sir began to draw a diagram on the board of how it happened.

Clues → Patterns → Ideas → Test → Final idea.
Clues - The clues which were useful to finding out what happened.

Patterns - Connecting clues to get a idea.

Idea - what we thought what happened.

Test - To test whether the other people in our group thought the idea was O.K.

Final idea - The final idea of what actually happened.

Somebody had wrote in their diary what has this got to do with Science?

"Luckily we got it all right. After we went to the front to discuss how we got our answer. Pete said we started by eliminating people. I said we started by finding out the clues which were useful and the ones which were not.
Sir began to draw a diagram on the board of how it happened.
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Clues - The clues which were useful to finding out what happened.
Patterns - Connecting clues to get a idea.
Idea - What we thought what happened.
Test - To test whether the other people in our group thought the idea was O.K.
Final idea - The final idea of what actually happened.
Somebody had wrote in their diary what has this got to do with Science?"

Robert

c. Comments from teachers

i) Rule spotting game

"Seemed to go quite well - after several good guesses one was given that was partly correct, which led to discussing the need to test guesses and reshape or reject the original one."

(ii) Murder mystery game

"A lot of productive arguing after a slow start. Problem solving strategies are not that well developed at this age (11). Interest level was high. Only one group found the solution (which I didn't confirm). The argument continued in the playground!"

"A proportion of the class thought the murder problem strange/pointless as they failed to make/understand the connection with science."

(iii) Both games

"They enjoyed the rule spotting game at a superficial level. They only wanted to get it right. I found it hard to draw out how they worked the answer out. Murder game - they started off quite interested but ended up finding it too hard. Only wanted to prove an individual's ideas were right to the rest of the group."

"Things went according to plan. About 20 minutes was allowed for the detective game - I thought that some groups may have finished in shorter time but this proved not to be the case - the whole class was working up to the bell."

"I felt that it went well - the pupils enjoyed the novel activity and handled the discussion element remarkably well. The word game proved to be a useful opener."

"Spotting the rule for the name game and the murder mystery generated more enthusiasm than I expected. No group properly solved the mystery but it generated good ideas about theory making."

(iv) Review of ideas

"Pupils had difficulty expressing how they had tackled the problem but they saw how their actions fitted into the pattern observation → organisation → theory → test → final theory."

5. Practical details

Murder mystery game

The game consists of a set of clues to a murder. Each group should be given a complete set of clues mounted separately on cards. They should be asked to address the following questions:

- Who was killed?
- Who was the murderer?
- What was the weapon?
- Where did the murder take place?
- At what time did the murder occur?
- What was the motive?

The clues for this game (provided below) should be cut up and stuck onto individual strips of card. Each discussion group needs a full set of clues; for a class of 24, with pupils working in groups of four, the teacher will require six complete sets of cards.

The only rule which groups must obey when attempting to solve the mystery is:

THERE SHOULD BE NO SHARING OF IDEAS BETWEEN DIFFERENT GROUPS.

Within each group pupils may use any strategies they wish in order to come up with an answer.

There are several ways in which the teacher might respond to pupil's theories about the murder. Two possibilities are:

- (i) Pupils may bring their answers to the teacher, who compares their ideas with the 'correct' answer (given with the clues) and simply tells each group whether they are 'right' or 'wrong'. If a group has come up with the 'right' answer, they are asked not to tell other groups, but to discuss among themselves the way in which they solved the mystery.

If the group's answer is 'wrong' or partly correct, they are not told which parts are correct or incorrect, but asked to try again.

- (ii) The teacher says that the answer is in a sealed envelope, which will be opened when everybody has come up with a theory. (The envelope in fact contains a blank card.) As groups come up with solutions they record them on poster paper. When all groups have a solution the posters are displayed and compared. The teacher then opens the envelope; there is no 'right' answer, but lots of theories, some of which seem to 'work' better than others. Though a more time consuming exercise than the first approach, this type of strategy does provide opportunities for more detailed discussion about the nature of scientific theories, and the criteria by which we judge theories to be good ones.

The Clues

When he was discovered dead, Mr. Black had a bullet hole in his thigh and a knife wound in his back.

Mr. Patel shot at an intruder in the block of flats where he lived at 12.00 midnight.

The Janitor reported to police that he saw Mr. Black at 12.15 a.m.

The bullet taken from Mr. Black's thigh matched the gun owned by Mr. Patel.

Only one bullet had been fired from Mr. Patel's gun.

When the Janitor saw Mr. Black, Mr. Black was bleeding slightly, but did not seem too badly hurt.

A knife with Mr. Black's blood on it was found in Miss Petty's garden.

The knife found in Miss Petty's garden had Mr. Hall's fingerprints on it.

Mr. Black had destroyed Mr. Patel's business by stealing all his customers.

The Janitor saw Mr. Black's wife go to Mr. Hall's flat at 11.30 p.m.

The Janitor said that Mr. Black's wife frequently left the block of flats with Mr. Hall.

Mr. Black's body was found in the park.

Mr. Black's body was found at 1.30 a.m.

Mr. Black had been dead for one hour when his body was found, according to a medical expert working with the police.

The Janitor saw Mr. Black go to Mr. Hall's room at 12.25 a.m.

The Janitor went off duty at 12.30 a.m.

It was obvious from the condition of Mr. Black's body that it had been dragged a long distance.

Miss Petty saw Mr. Black go to Mr. Patel's block of flats at 11.55 p.m.

Mr. Black's wife disappeared after the murder.

Police were unable to locate Mr. Hall after the murder.

When police tried to locate Mr. Patel after the murder, they discovered that he had disappeared.

The Janitor said that Miss Petty was in the Entrance Hall of the block of flats when he went off duty.

Miss Petty often followed Mr. Black.

Mr. Patel had told Mr. Black that he was going to kill him.

Miss Petty said that nobody left the block of flats between 12.25 a.m. and 12.45 a.m.

Mr. Black's blood stains were found in Mr. Hall's car.

Mr. Black's blood stains were found on the carpet in the hall outside Mr. Patel's

One possible answer:

After receiving a superficial gunshot wound from Mr. Patel, Mr. Black went to Mr. Hall's flat where he was killed by Mr. Hall with a knife at 12.30 a.m. because Mr. Hall was in love with Mr. Black's wife.

A homework exercise on scientific theories is given on the next page.

There were two puzzling mysteries in a school science lab. No-one could solve them. These were the mysteries:

1. There were no lead pencils to be found, no matter how many people searched.
2. The pencil sharpener was always full of pencil shavings.

The situation became so serious that a group of teachers and pupils was appointed by the headteacher to find out what was going on. They found their task very difficult because everyone was fussing about what was happening to the pencils. Finally, they solved the mystery.

This is what they said:

"There is a simple explanation. In the lab sinks, their theory went, live a lot of little people. They are called PLOGS. At night, when no-one is there, they come out of the sinks. They collect up all the pencils, then they go to the pencil sharpener and grind them all up. Then they return to their sinks."

Everyone was pleased with this theory because it could explain both mysteries.

Questions

1. How could you test this theory to find out if it works?
2. Suppose there are no PLOGS in the sinks, how else would you explain the two mysteries?
3. Can you ever be sure that there are no PLOGS?

PART C:

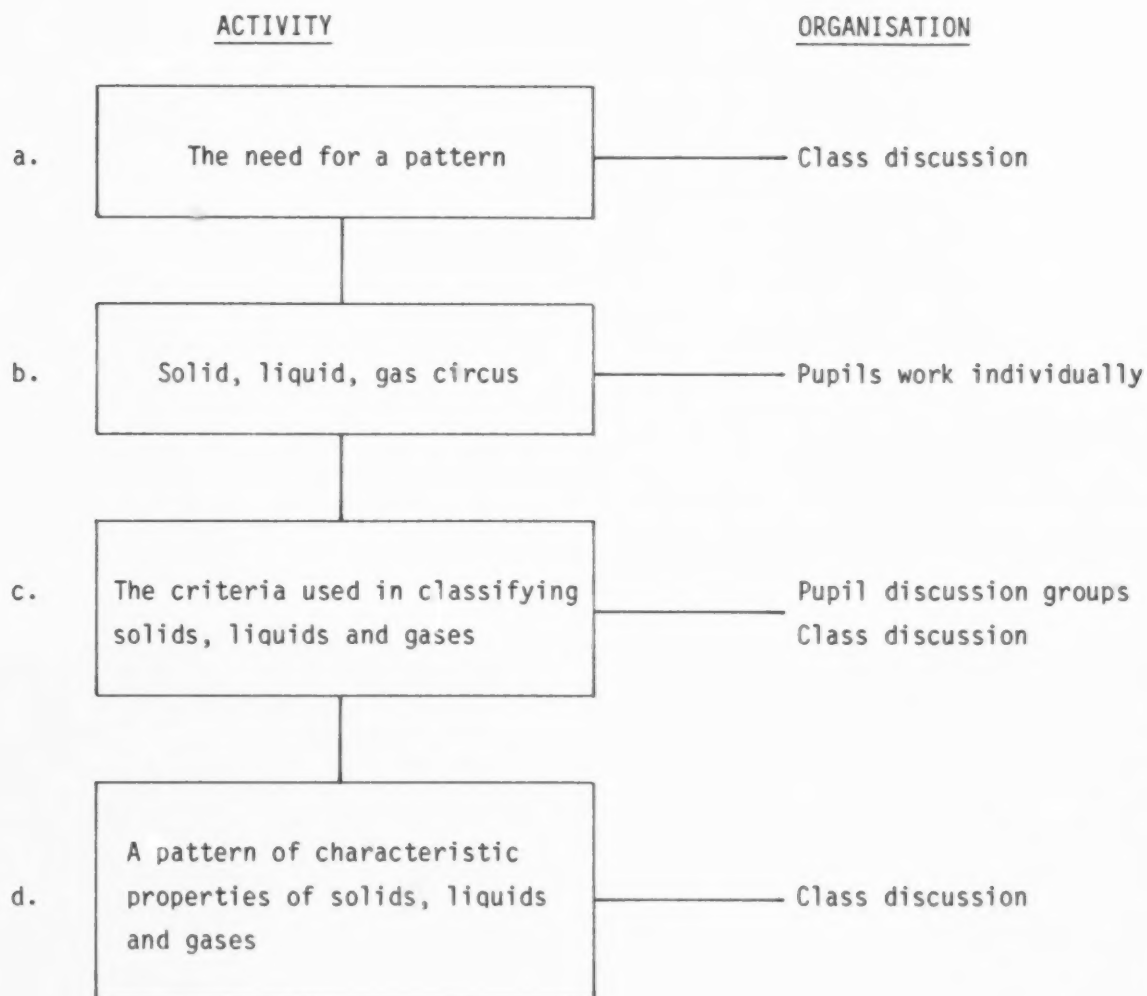
**A PATTERN OF PROPERTIES FOR SOLIDS,
LIQUIDS AND GASES**

1. Intentions and underlying thinking

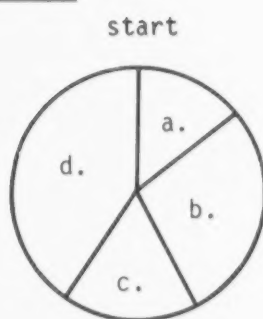
In Part B, the link between patterns in data and theory making was considered. Attention is now focused back upon 'matter' (the stuff which is all around us) and a search for patterns in the behaviour of solids, liquids and gases is undertaken.

2. Action plan

Part C is divided into a number of activities:



TIMING



Total time for the section = approximately $1\frac{1}{2}$ double lessons
($1\frac{1}{2} \times 80$ minutes)

- a. = The need for a pattern
- b. = Solid, liquid, gas circus
- c. = The criteria used in classifying solids, liquids, gases
- d. = A pattern of properties

3. The activities

a. The need for a pattern

(i) The activity

The teacher sets the scene for this phase of the work. A number of points need to be raised either by the teacher, or by eliciting responses from the pupils. It should be noted that the teacher is making much more of a formal input than has occurred at any point to date.

Ideas which need to be put across to pupils include the following:

- The work on Scientific Theory (Part B) might suggest that searching for patterns in data could be a useful strategy in starting to develop a theory.
- We are returning now to the context of the present work - 'a study of matter' (the stuff with is all around us).
- Already, a considerable amount of data has been collected (Section A: Elicitation) which describes how matter behaves in a variety of circumstances - refer to the 'Elicitation Posters' on the laboratory wall.
- These posters present lots of ideas which attempt to explain why the substances behave as they do. But, there are at least as many different explanations as there are phenomena under consideration.
- Would it be possible to develop one single theory which could explain all of these apparently unconnected phenomena? This is the challenge which the pupils will take up shortly - 'to have a go at developing their own theories as to what matter is like inside'.
- In preparation for this theory making challenge, pupils might, first of all, work at identifying patterns in the behaviour of matter.

Note: It may be worth reminding students of the copper sulphate/water demonstration at this point, asking the class if they think that there has been any change. The teacher should not, however, make any comments at this stage.

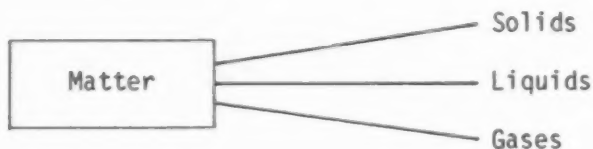
(ii) Organisation

Pupils should be asked to sit at the front of the class while this discussion takes place.

b. Solid, liquid, gas circus

(i) The activity

Having established that one way forward would be to search for patterns in the behaviour of matter, then a useful starting point is one which recognises that matter can be classified:



Other starting points would be equally valid, e.g. matter is either fluid or not fluid. The pupils do, however, appear to be at ease with the notion that:

'All stuff is either solid, liquid or gas'

Pupils are given the opportunity to try to classify a range of substances as either solid, liquid or gas.

(ii) Organisation of the circus

A large number of items (maybe 25-30) are set out around the laboratory. The pupils are asked to examine each item and to classify it as either solid, liquid or gas. Pupils work individually and record their answers on paper. (Details for the circus are given on pages 96 to 98.)

(iii) Review of the circus

The review provides the opportunity for pupils to see whether they 'got them all correct'. It also provides the opportunity for the teacher to see whether there are any problems in applying the solid, liquid, gas classification.

The teacher should read out the list of 'correct' answers and, as a starting point to discussion, ask for the numbers of any items where the pupils' classification differed from that of the teacher.

Experience has shown that the majority of pupils get most of the items correct. Substances which have caused problems include:

cloths	powders
fabrics	foams

It seems quite common for pupils to deal with these problematical substances by employing a process of elimination. Thus a powder may be judged to be a solid because:

"it isn't a liquid or a gas."

The teacher may spend a little time in discussing substances which have created difficulties. However, the principal message which almost inevitably will come out of the circus is that the pupils:

"are pretty good at sorting out solids, liquids and gases!"

c. The criteria used in classifying solids, liquids and gases

(i) Purpose

Having established that the pupils are skilled in identifying solids, liquids and gases, they are now challenged with three questions:

Each pupil group is asked to consider:

1. What is it about a SOLID which makes it a SOLID?
2. What is it about a LIQUID which makes it a LIQUID?
3. What is it about a GAS which makes it a GAS?

Experience has shown that pupils can classify solids, liquids and gases with confidence and accuracy. However this next exercise, of identifying the criteria which they use in that process, has created far more difficulty. They really are forced to consider their own thoughts and to try and work out just how they are able to differentiate between the three states. To provide some help the teacher should refer them back to the elicitation activities and the posters displayed on the wall:

"Refer back to your original posters also. They may include some useful ideas for sorting out between the solids, liquids, gases."

Note: It is inadvisable to use the phrase 'the properties of solids, liquids and gases' at this stage, as many pupils do not appreciate the meaning which the teacher gives to the word 'property'.

(ii) Organisation

Pupils organise themselves into their discussion groups and are asked to apply themselves to the three questions. Each group is asked to jot down their ideas, in three columns, on a piece of paper:

I know this is a SOLID because:	I know this is a LIQUID because:	I know this is a GAS because:

An example of group work is shown below:

I know this is a Solid Because:-	I know this is a Liquid Because:-	I know this is a Gas Because:-
1 Heavy 2 Hard 3 Tough 4 Usually Metals and Stone 5 It can hurt 6 If it drops it can make a loud bang	1 Wet runny 2 Wet 3 Light 4 Easy to shake 5,	1 Invisible 2 See through it 3 Usually found in a solid 4 Walk through it 5,

I know this is a
Solid Because:-

1. Heavy
2. Hard
3. Tough
4. Usually Metals
and Stone
5. it can hurt
6. If it drops it can
make a loud bang

I know this is a
Liquid Because:-

1. It's runny
2. Wet
3. Light
4. Easy to shake
- 5.

I know this is a
Gas Because:-

1. Invisible
2. See through it
3. Usually found in
a solid
4. Walk through it
- 5.

(iii) Collection of ideas

As groups finish, they might be asked to bring out their lists of ideas to the teacher for display. This enables other groups to share their ideas with other members of the class before any formal discussion and review takes place.

One way of displaying ideas might be for the teacher to have already prepared a table on the blackboard or overhead projector onto which he/she or the pupils can add ideas as the lists are finished. Table 4 shows the range of ideas produced by one class.

TABLE 4. AN EXAMPLE OF IDEAS FROM ONE CLASS ABOUT SOLIDS, LIQUIDS AND GASES

I know this is a SOLID because:	I know this is a LIQUID because:	I know this is a GAS because:
hard - or soft can't be evaporated don't move around got mass can hold it float - some don't dry can't change shape always visible cannot be compressed can be shaped can be made into a liquid can't be polluted	moves freely in air evaporates into a gas when heated got mass wet will run off unless kept in a container (separates when released) visible you can't shape a liquid can be polluted (air) settles with a flat surface (apart from mercury)	can't see it unless coloured if let out can mingle in the air (separates when released) light all around us cannot feel it can be inhaled can be compressed you can't shape a gas can be changed into a liquid doesn't weigh anything/not very much can escape through smallest crack

As pupils' ideas begin to appear on the board, the teacher may start to feel rather uncomfortable about some of them 'solids are hard or soft' is not the type of criterion which many science teachers would wish to see in use as a way of distinguishing solids from liquids and gases!

These ideas, however, represent the pupils' views, and as such must all be recorded, however strange some of them might seem. An opportunity to reflect upon them, and consider their relative merits, will be provided in the next activity.

Note: In order to provide time for the teacher to reflect on the range of ideas which pupils have brought forward, and ways in which these ideas might be reviewed and evaluated, it has been found useful to organise the timing in such a way that the ideas are collected together AT THE END OF A LESSON.

d. A pattern of properties of solids, liquids and gases

(i) Purpose

Having generated a number of ideas about the ways in which solids, liquids and gases can be distinguished from each other, the class is now faced with two tasks:

- to review each idea in turn and consider whether it is valid
- having discussed the ideas which the class wishes to reject, and those it wishes to retain, to then consider whether there are any patterns in properties across the three states, solid, liquid and gas.

(ii) Organisation

This session should be run as a class discussion, with the pupils arranged around the board or overhead projector on which their collected ideas are displayed. The teacher's role in this exercise is not an easy one.

While keeping in mind the goal of obtaining a recognisable table of the properties of solids, liquids and gases he/she must ensure that pupils' views are taken into account and that any pattern finally agreed on represents the consensus view of the class rather than the teacher's own imposed views. In this discussion, therefore, the teacher will be acting as something more than neutral chairperson, and needs to actively question pupils and encourage them to defend their ideas. It is not appropriate, however, for the teacher to simply tell the pupils that their ideas are wrong and present them with the correct answer.

(iii) Timing

The timing of this discussion will depend entirely on the class and the level at which they are ready to participate. If the class is actively involved and the teacher works from their ideas a lengthy discussion may result (between 20 minutes and an hour!).

It is crucial that teachers are responsive to the needs of their own pupils at this stage. Prolonging discussion when many pupils have lost interest can be counter-productive, as can cutting discussion short in order to impose the 'right answer'.

(iv) The negotiation of the pattern

TASK ONE: Deleting inappropriate criteria

Each of the listed items is considered in turn and the teacher asks the pupils for comments as to whether or not the items are correct/useful/worth keeping .. or not.

From the example shown in table 4 several items were either crossed out or amended by the class. These items and reasons given for their deletion or amendment are shown in table 5.

TABLE 5. ITEMS DELETED FROM THE PATTERN

STATE	Item	Pupil Comments
SOLID	hard or soft (deleted)	it's not a good way of telling a solid if it can be hard <u>or</u> soft
	float - some don't (deleted)	solids float - but some don't - that's daft!
	can't be polluted (deleted)	yes they can!
LIQUID	none deleted or amended	
GAS	all around us (amended)	<u>air</u> is all around us
	doesn't weigh anything (amended)	not true. Gases don't weigh very much

TASK TWO: Looking for patterns

Having initially 'tidied up' the data the class now look for patterns in the properties across the three states. Prior to teaching this lesson, the teacher will undoubtedly have his/her own ideas relating to what constitutes a pattern of practical use in theory building. Such a pattern might include the following ideas:

Property	Solid	Liquid	Gas
Shape	fixed	of container	spreads to fill container
Strength	strong	limited strength	no strength
Compressibility	zero/low	zero/low	high
Density	high/low	high/low	very low

It is useful for the teacher to have such a pattern or scheme in mind. On no account, however, should the teacher impose this view prematurely and thereby remove the chance for pupils to consider and talk about other possible patterns. Each pupil should have the opportunity to go through the arguments and counter-arguments which might lead to the kind of pattern which the teacher has in mind.

During one class discussion, for example, the following issues were raised:

The property of shape - This was suggested by a pupil and the pattern across the three states established reasonably quickly. Some of the alternative ideas raised by pupils during discussion included:

"ice is water and it has a fixed shape"
(therefore liquids (water) can have a fixed shape)

"the gas inside a sealed container has a fixed shape"

"a sponge doesn't have a fixed shape - you can squash it"
(therefore solids do not have a fixed shape)

All of these notions were argued against by other pupils.

Heaviness - Again, raised by a pupil. It was generally felt that solids and liquids could be heavy or light but that gases in comparison were light. Some of the ideas raised by pupils in opposition to this suggestion included:

"you can't say how heavy something is - it depends on how much of it you have"

"air isn't light - look at the air pressure"

"this isn't a very good way of deciding between them - solids and liquids can both be heavy or light."

Compression - This was suggested by a pupil who was thinking back to the syringe activity (page 50). She had remembered that gases can be squashed whereas solids and liquids cannot.

"that's a bit like the heaviness one - solids and liquids are the same and gases are different"

"solids can be squashed - what about plasticine and sponges and cloth" (This issue may be partly resolved discussing the presence of air between fibres in cloth, cotton wool etc.).

Strength - This may not appear on the pupils' original lists of properties. In some cases, the teacher introduced the idea that strength may be worth looking at.

Solids were generally considered to be strong - strong enough to hold up a load - strong enough to support themselves. One pupil referred back to the razor blade activity (page 52) in suggesting that "liquids do have a little strength". Another pupil referred to the way that droplets of water retain their shape - holding themselves together. All agreed that "people walking on water was another matter altogether". It was felt that gases had no strength at all ... but "what about the wind - knocking down trees?" asked one girl.

For this class, the pupils and teacher were able to work together to produce the following pattern:

Property	Solid	Liquid	Gas
Shape	fixed	of container	none - it spreads
Compress	can't	can't	can
Heavyness	high/low	high/low	low
Strength	strong	a little strength	no strength at all

Note: Movement/diffusion was not introduced at this stage. Nor was there any attempt to encourage the use of 'scientific' words e.g. density instead of heaviness.

The teacher should keep a copy of the final pattern - it will be used in the next section.

4. Reflections on Part C: A pattern of properties for solids, liquids and gases

a. General issues

It may be helpful to be aware of the following:

- Though pupils enjoy the circus of activities and to a lesser extent the group work on discussing criteria to be used in classification, there is no doubt that some find the class discussion very heavy going (see diary extracts below). It is important to encourage all members of the class to participate actively in this, so that they feel that the final pattern which emerges is theirs; that they have a personal stake in it.
- Some teachers were concerned that a recognisable pattern would fail to emerge if the class were given freedom to stipulate what they wished to include in it. By and large these concerns were unfounded. A certain amount of compromise by both pupils and teacher usually produced something that was satisfactory to both parties.
- A great deal of flexibility is required from the teacher, as timings for this section are very difficult to predict. Once the discussion starts, there is no knowing where or when it will end!

b. Comments from pupils

(i) Solids, liquids, gases circus

In todays lesson we got 28 diffrent things and we had to find out if they were solid, liquid or gas my self I thought it was very intresting but very easy the way I worked out the ones I was not sure about like a cloth it didnt seem solid but it wasnt gas and it wasnt liquid it must have been solid I dont see how people can get them wrong if they work them out like I Do but still very intresting

"In todays lesson we got 28 diffrent things and we had to find out if they were solid, liquid or Gas my self I thought it was very intresting but very easy the way I worked out the ones I was not sure about like a cloth it didnt seem solid but it wasnt Gas and it wasnt Liquid it must have been solid I dont see how people can get them wrong if they work them out like I Do but still very intresting."

After this we, ~~for~~ for the first time worked alone. We went round 28 different items and had to write whether these items were liquid (L) Gas (G) or solid (S). They were everyday objects that were used. After this had been completed we tick our answers and "Not really suprisingly" I got them all right. I found this work very easy, that work not the next bit.

We had to write down why we could tell it was an object (S) (G) or (L). I suppose knowing what a thing is, is taken for granted because explaining this was very difficult. We were only able to write a few words about each.

"After this we, for the first time worked alone. We went round 28 different items and had to write whether these items were liquid (L) Gas (G) or Solid (S). They were everyday objects that were used. When this had been completed we tick our answers and "Not really suprisingly" I got them all right. I found this work very easy, that work not the next bit. We had to write down why we could tell it was an object (S) (G) or (L). I suppose knowing what a thing is, is taken for granted because explaining this was very difficult. We were only able to write a few words about each."

Shirley

PHISICAL SCIENCE

In last weeks lesson we wrought about what liquid, solids ang Gas Mr Scott put on the board all the diffrent things all the class had put on there paper then we had cross of the ones we didnt think true and we had an argument about solid ~~are~~ cannt be squached I dont think they can because cotton wool and a sponge can be squashed but it is the air that is been squashed cotton wool is ~~at~~ nearly all air

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Darren

Today's lesson was pretty boring. The whole lesson was taken up by talking and taking out ideas about the differences between Solids, gases and liquids. Then we talked about the ideas that the 3 had in common. I can't decide what they have in common its just as one of those things that you don't think about you just know. I hope sir knows what they have in common because I can't decide.

"Today's lesson was pretty boring. The whole lesson was taken up by talking and taking out ideas about the differences between Solids, gases and liquids. Then we talked about the ideas that the 3 had in common. I can't decide what they have in common its just one of those things that you don't think about you just know. I hope sir knows what they have in common because I can't decide."

Yogendra

c. Comments from teachers

(i) On the Solids, Liquids, Gases Circus

"Fairly easy to organise. Whole class found this interesting and worthwhile. They and I felt it was a useful exercise. Many had clearly never really looked at different liquids or gases."

"I was happy with the lesson overall and would not want particularly to change anything. In the solids, liquids, gas circus the majority of pupils were 100% successful. Powders and cloth were identified as solids by a process of elimination:

- not a liquid
- not a gas
- so must be a solid!"

(ii) Group work on identifying criteria used in classification

"When they worked in groups to sort out their ideas on solids, liquids, gases it went well Arguments broke out over some powders and fibres."

(iii) Discussion to negotiate the pattern

"I was pleasantly surprised by the lesson as a whole. I had thought that arriving at a pattern may have been more difficult. After hearing all their suggestions, there was a good pattern."

"As might be expected, the teacher directed 'class discussion' did not involve the whole class. Imposing 'my pattern' on their data was not particularly easy - I found myself defending 'my position' whilst trying not to let it look like that. The tidy patterns that I wished to introduce were frequently questioned by considerations of 'rogue'/'everyday' properties of solids, liquids and gases."

5. Practical details

The solids, liquids, gases circus

Requirements

- Paper for pupils.
- Numbered cards one to put next to each substance. Between 25 and 40 substances should be laid out around the room.
- Substances - suggestions below. An effort should be made to avoid using too many 'scientific' substances.

Non-Problematic Solids

- * Metals - various - metal objects are much more interesting than strips of metal
- * Plastics - as above, e.g. perspex blocks, polythene carrier bags
- * Glass
- * Wax
- * A house brick
- * Pottery
- * Crystals
- * Rock
- * Classroom chalk
- * Paper
- * Aluminium foil
- * Wood

'Solids' Which May Raise Questions

- * Powders - chemicals and 'household' e.g. flour, soapflakes, sand, soil
- * Fabrics - cotton wool, wool, cotton, nylon
- * Wire/steel wool
- * Iron filings
- * Plasticine/blu-tack
- * Rubber washing-up glove
- * Jelly

Non-Problematic Liquids

- * Water/coloured solutions
- * Ink
- * Wine
- * Tea/Coffee
- * Milk
- * Oils (various)
- * Glycerine

'Fluids' Which May Raise Questions

- * Toothpaste
- * Swarfega
- * Vaseline
- * Shaving foam
- * Treacle

Gases

Much more difficult. Teachers used air/oxygen and bromine/nitrogen dioxide in sealed containers.

Pupils are asked to examine each substance, write its number on their bit of paper, identify it if possible and classify it as solid (S), liquid (L) or gas (G).

An example of the range of materials used by one teacher is shown in table 6. Every pupil in this class got all 25 'right'. (Most, however, had much more trouble when asked to identify how they knew that these substances were solids, liquids or gases.)

TABLE 6. THE SOLID, LIQUID, GAS CIRCUS USED BY ONE TEACHER

1. Tea towels	S
2. Glycerine	L
3. Metal filings	S
4. Detergent	L
5. Iron powder	S
6. Oil	L
7. Balls	S
8. Water	L
9. Rock salt	S
10. Steel wool	S
11. Plastic cone	S
12. Bow saw	S
13. Plastic bag	S
14. Brown gas	G
15. Cotton wool	S
16. Rubber band	S
17. Big weight	S
18. Foam, polystyrene	S
19. Green liquid	L
20. Sunflower seed	S
21. Copper strip	S
22. Rubber glove	S
23. Brown gas	G
24. Beaker	S
25. Air	G

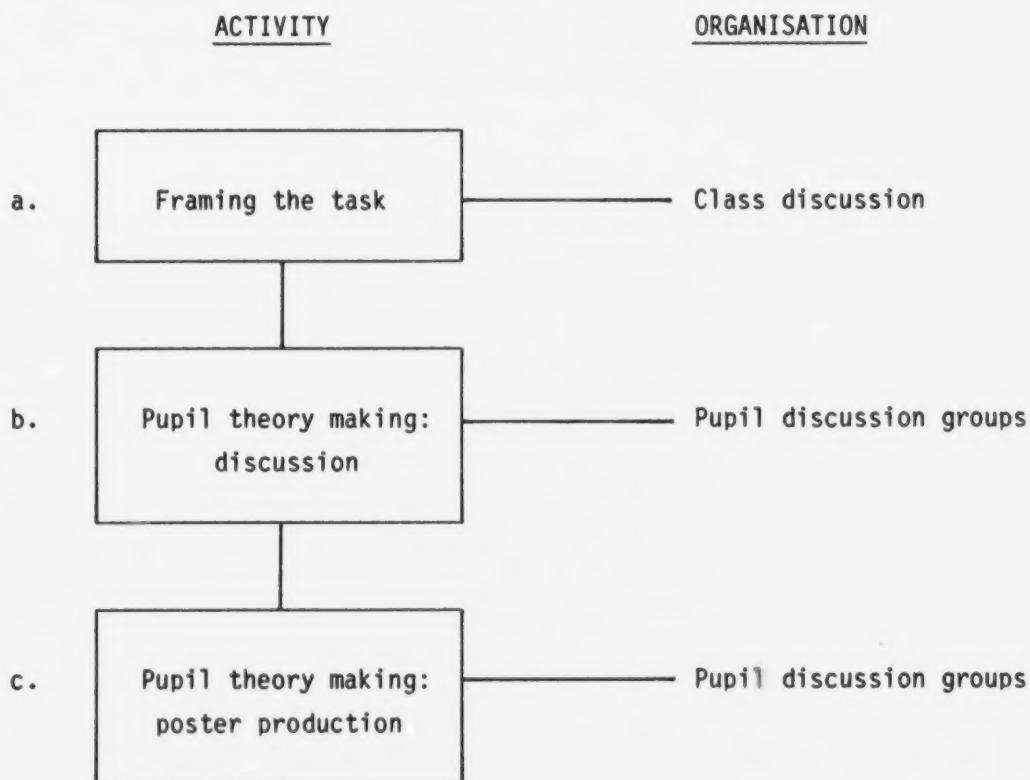
PART D:
PUPIL THEORY MAKING

1. Intentions and underlying thinking

Pupils draw upon the ideas considered in the first three parts of the scheme and develop their own theories about the nature of matter. It is recognised that as well as referring to ideas raised during the last few lessons, pupils may also draw upon other ideas which they might have come across outside these lessons and outside school (e.g. through reading, watching science programmes on television, talking with parents, friends, sisters, brothers and other teachers).

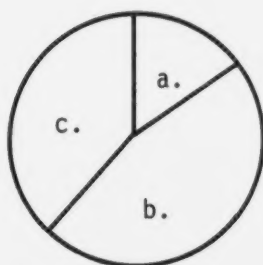
2. Action plan

Part D is divided into a number of activities:



TIMING

Total time for the section = approximately $1/1\frac{1}{2}$ double lessons
($1/1\frac{1}{2} \times 80$ minutes)



- a. = Framing the task
- b. = Pupil theory making: discussion
- c. = Pupil theory making: poster production

Note: Pupils may have completed their posters by the end of a double lesson, but it is worth allowing time at the start of the next lesson if this is needed.

3. The activities

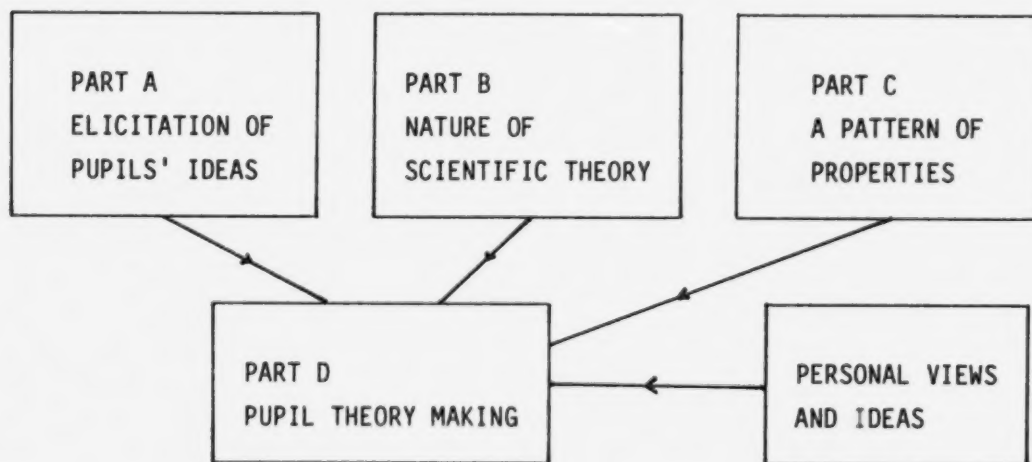
a. Framing the task

(i) Purpose

The teacher describes the task which pupils will be asked to carry out in groups (to come up with a theory of their own which explains the nature and behaviour of solids, liquids and gases) and sets the scene for the group work, reminding them of some of the ideas from earlier lessons which they may wish to draw on.

(ii) Context of the theory making

Pupil theory making draws upon ideas introduced in the first three sections of the course - in addition to any other ideas that the pupils will undoubtedly bring to the problem, i.e:



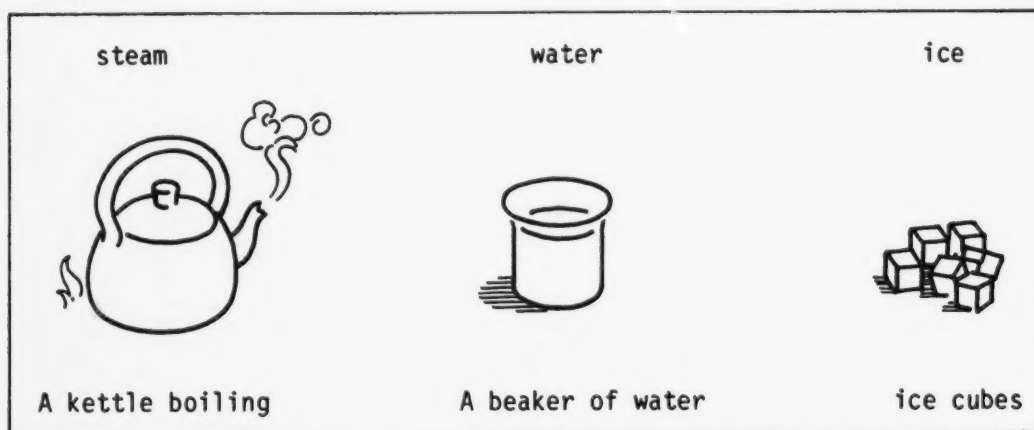
Teacher and pupils might usefully review the ideas generated in the first three sections of the course:

- the ideas from the elicitation activities (as illustrated on the posters)
- the progress of the copper sulphate/water demonstration
- the view of scientific theory making
- the pattern of properties of solids, liquids, gases.

It may be helpful for the teacher to have drawn out on the board both the class view of scientific theory (a flow chart such as that shown in Part C) and the class consensus pattern of properties before the start of the lesson. Groups can then refer to these during discussion.

(iii) A final focus for the theory making

This could be achieved by drawing attention to the three states of a very common material - water. The teacher might set out on the bench:



"Ice, water steam - it's all the same stuff ... and yet it's so different. Ice - a solid. Water - a liquid. Steam - a gas. When ice melts to water - nothing extra is added - and yet water is so different from ice. How might this same stuff be differently arranged inside to give the contrasting properties of solid, liquid and gas?"

"Imagine that you could put on a pair of microscopic spectacles which would allow you to see right inside the ice, water and steam. Build up your own theory as to what they must be like inside. A theory which would apply to any solid, liquid or gas."

Note: It must be emphasised that, at this stage, no mention is made, by the teacher, of particles, atoms or molecules. If pupils have used these words, earlier in the scheme, the teacher simply accepts them as ideas which are as valid (but no more so) than any others put forward by the class.

A number of teachers have pointed out that:

- some pupils may not be aware that ice, water, steam are 'all the same stuff'
- problems may be created by pupil awareness of the anomalous behaviour of water on freezing.

b. Pupil theory making: discussion

Pupils are asked to work in their normal discussion groups. By this time the groups should be well established.

The groups should be instructed to:

- DISCUSS all of the points raised in the introduction to the lesson
- propose their own theories as to the nature of solids, liquids and gases
- draft out, in rough, ideas which are agreed upon by the group. (The teacher might stress the importance of attempting to link any statements/claims to relevant ideas from previous lessons.)

It might be useful for the teacher to set a time limit on this activity, in order to focus the pupils. Between 20 and 30 minutes should be an adequate amount of time. At this stage, pupils should also be informed that:

- at the end of the discussion they will be asked to produce a poster summarising their ideas
- they should select one person from the group to 'report back' on their ideas to the rest of the class.

c. Pupil theory making: poster production

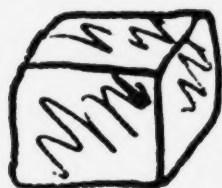
When each group has completed their discussions and jotted down their ideas in rough, then they should be given a large piece of paper and asked to produce a poster on which the main elements of their theory are summarised. Once again it might be useful for the teacher to set a time limit on this activity (e.g. 15 to 20 minutes) ask that the posters should be clear and tidy but not necessarily 'works of art'.

Examples of pupil posters are shown on the following pages.

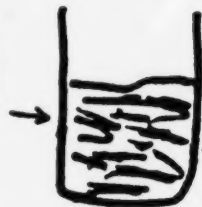
SOLID

(Hot)
Eg Metal - liquid - Metal

You can hold and see solids. They are stronger than liquids and gases. They have a fixed shape unless you do something to them. They can be heavy or light



Ice



Water



Steam

LIQUID

Eg. WATER - ICE - STEAM

Liquids take the shape of their container. They can have a little strength.

Liquids are squashy. They can be light or heavy. They are the same inside as they are outside (we think).

GAS

Eg Fog - Window Frost - Water

Steam - Condensation - Water - ICE

Gases are the same outside as they are in, they can be transformed depending on what you do to them. Example shown above. They have no shape they just spread around. They are weaker than solids and liquids

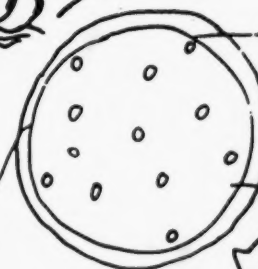
'SOLIDS' 'LIQUIDS'

THE MOLECULES OF A SOLID, ARE ALSO HELD TOGETHER BY SOME UNKNOWN FORCE.

THE MOLECULES OF A SOLID, ARE TIGHTLY PACKED AND LINKED STRONGLY TOGETHER BY AN UNKNOWN FORCE. THIS MAKES THE SUBSTANCE SOLID AND STRONG.

THE MOLECULES OF A LIQUID, ALSO HELD TOGETHER BY AN UNKNOWN FORCE.

THE MOLECULES OF A LIQUID ARE NOT SO PACKED TOGETHER SO TIGHTLY, AND THEIR LINKS ARE NOT AS STRONG, SO THEY ARE IN A 'LIQUIDY' FORM WHICH REGAINS THE FORM OF ITS SURFACE. (IT COLLAPSES OUT ON ITS SURFACE.)



THE MOLECULES OF A GAS FREE TO ROAM AROUND

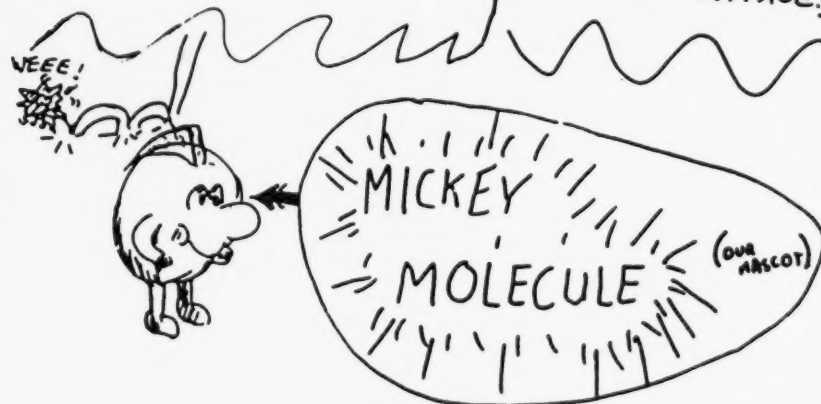
THE LITTLE IS TO REPRESENT THE SPACE YOU WOULD SEE THROUGH A MICROSCOPE



GASES

THE MOLECULES OF A GAS, ARE NOT PACKED AT ALL, AND SINCE THEY HAVE NO LINKS, THEY ARE FREE TO ROAM AROUND, AND CAN BE COMPRESSED AND SQUASHED TO WHATEVER SHAPE THEIR SURROUNDINGS IS.

119



106

120

Solids

are
Heavy or Light
Fixed shape
Cannot be compressed
Strong

The molecules/parts that make up shape and are extremely small / are packed tightly together.

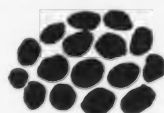


molecules packed tightly together.

Liquids

are
Heavy or light
Take shape of container
Compress a bit
A little strength

The molecules are not tightly packed together but are not very spread out.



Molecules spread out a little bit

Gases

are
Light
Spreads out
Can be compressed
no strength at all

The molecules are spread out all over the place



molecules spread out
All this information can

Explain:.....

SOLIDS

From

Solid.

Jo.

Shaz

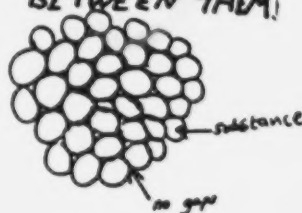
WE THINK SOLIDS LOOK THE SAME ALL THE WAY THROUGH.

THE PARTICLES OF THE SUBSTANCE HAVE NO DISTANCE BETWEEN THEM!

THE DIAGRAM SHOWS THAT THE PARTICLES CANNOT

BE SQUISHED, ANY FURTHER THAN THEY ARE.

SOLIDS CANNOT CHANGE SHAPE VERY EASILY.



LIQUIDS

THE PARTICLES OF THE SUBSTANCE ARE THE SAME ALL THE WAY

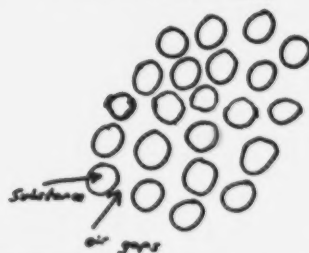
THROUGH BUT THERE IS A GAP BETWEEN EACH PARTICLE. IN

THESE GAPS THERE IS AIR. WE THINK THIS

BECAUSE WE CAN SQUASH THEM AND WHEN

YOU POUR INTO A CONTAINER IT TAKES THE

SHAPE OF THE CONTAINER.



GASES

WE THINK THE PARTICLES ARE THE SAME ALL THE WAY

THROUGH BUT THERE IS A BIG AIR GAP BETWEEN EACH PARTICLE.

WE KNOW THIS BECAUSE GASES ARE LIGHT AND

ARE VERY SQUASHY. GASES ARE ALWAYS IN THE

~~ATMOSPHERE~~ ATMOSPHERE AND YOU CANNOT COLLECT

THEM IN A CONTAINER VERY EASY



4. Reflections on Part D: Pupil theory making

a. General comments

Comments from both pupils and teachers indicate that in general this section of the scheme "went well". The following points however may be worth bearing in mind:

- pupils need to be clear about the purpose of the activity before the discussion session starts. It is well worth spending some time (perhaps 15 minutes) at the start of the lesson focussing them on the task
- during group discussion and poster production, the teacher should circulate around groups encouraging them to think ideas through and to draw on all the ideas which have come up in the last few lessons. He/she should not, however, attempt to prompt the groups or push them in the direction of the correct scientific answer. Opportunities for direct intervention by the teacher will be available later
- in most classes some groups (if not all) come up with theories which mention particles, atoms or molecules. This gives the teacher a starting point from which to develop the scientific ideas in the next lesson. To date, no class using the scheme has produced a set of posters which contain only macroscopic ideas. Some suggestions for dealing with such a possibility (though it is extremely unlikely) are, however, included in the next part
- pupils should be well on their way toward completing their posters by the end of a double lesson, though a small amount of time for 'finishing off' may be required at the start of the next lesson. The teacher should take the opportunity to review the posters before the start of the next lesson, in order to assist in planning it.

b. Comments from pupils

Mr Scott started off today's lesson by melting a piece of ice over the steam coming out of a kettle it melted. He did this for an example of the next thing we were going to do. We had to do another poster. On the poster we were to say what was inside a solid, liquid or gas. The groups we organised before were to do this together. Our group came up with the idea that molecules were inside this. We said they

were microscopic. Next we had to say ~~what~~ why the solids have strength and liquids some strength but gases little strength.

We did this for compression, weight and I have forgotten the other one.

Solids are strong because the molecules are packed tightly together and so hold up the weight. Liquids are quite strong because the molecules are a bit spaced out but not wide apart like in gas which has only a little strength. Solids cannot be compressed because the molecules are already packed tightly together. They are also heavy or light because if they are packed tight there is more of them in one area. Sponge and such like are light though, so although it is a solid the molecules are spaced apart a bit.

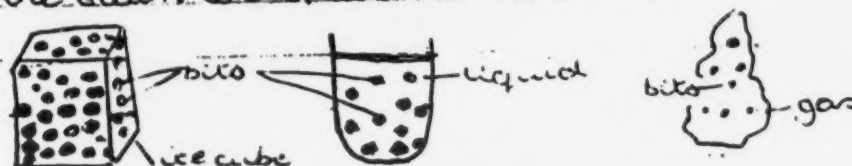
"Mr. Scott started off today's lesson by melting a piece of ice over the steam coming out of a kettle it melted. He did this for an example of the next thing we were going to do. We had to do another poster. On the poster we were to say what was inside a solid, liquid or gas. The groups we organised before were to do this together. Our group came up with the idea that molecules were inside this. We said they were microscopic. Next we had to say why the solids have strength and liquids some strength but gases little strength. We did this for compression, weight and I have forgotten the other one. Solids are strong because the molecules are packed tightly together and so hold up the weight. Liquids are quite strong because the molecules are a bit spaced out but not wide apart like in gas which has only a little strength. Solids cannot be compressed because the molecules are already packed tightly together. They are also heavy or light because if they are packed tight there is more of them in one area. Sponge and such like are light though, so although it is a solid the molecules are spaced apart a bit."

Amanda

Today the lesson started with us all round the front bench looking at the table which we made out on Friday. We went over all the things written down to remind us. We were then asked if we could find out why steam, water and an ice-cube were made out of water but were so different. We had to get into our groups of fours and discuss our ideas.

We discussed all our ideas. This was very hard I thought because the explanation had to fit all of the three things.

We finally came to a decision. The solid contains 'bits' which are packed together. The liquid has these 'bits' which are spread out in between air. The 'bits' in the steam are spread out even more.



"Today the lesson started with us all round the front bench looking at the table which we made out on Friday. We went over all the things written down to remind us. We were then asked if we would find out why steam, water and an ice-cube were made out of water but were so different. We had to get into our groups of fours and discuss our ideas.

We discussed all our ideas. This was very hard I thought because the explanation had to fit all of the three things.

We finally came to a decision. The solid contains 'bits' which are packed together. The liquid has these 'bits' which are spread out in between air. The 'bits' in the steam are spread out even more."

Judith

After this we separated into our groups and produced a poster showing what we think the differences ^{are} and also the things that solids, liquids and gases have in common. We haven't quite finished the poster yet.

I think that liquids and solids are much closer together (with things in common) than gases are.

I think this is because of the molecules inside. In solids they are very close together and are all touching. In liquids they are fairly close together but do not quite touch. The molecules in gases are very spaced out.

"After this we separated into our groups and produced a poster showing what we think the differences are and also the things that solids, liquids and gases have in common. We haven't quite finished the poster yet.

I think that liquids and solids are much closer together (with things in common) than gases are. I think this is because of the molecules inside. In solids they are very close together and are all touching. In liquids they are fairly close together but do not quite touch. The molecules in gases are very spaced out."

Jonathan

c. Comments from teachers

"I started this lesson off with a sense of unease - not knowing where it would end!"

"This discussion was much more purposeful and on task than previous ones. Two of the groups (11 year olds) were even using particulate ideas and the other groups were able to produce cogent ideas - although we're a bit stuck with the idea that everything has air in it."

"Pupil theory making was initially set up within the bounds of a suggested 15-20 minute time limit. This was, with this particular class, far too short. In the event they were usefully occupied for 35-40 minutes."

"I felt that it went very well. The pupil theory making groups operated successfully - there appeared to be a high level of involvement throughout the class - including usually 'reluctant scientists'."

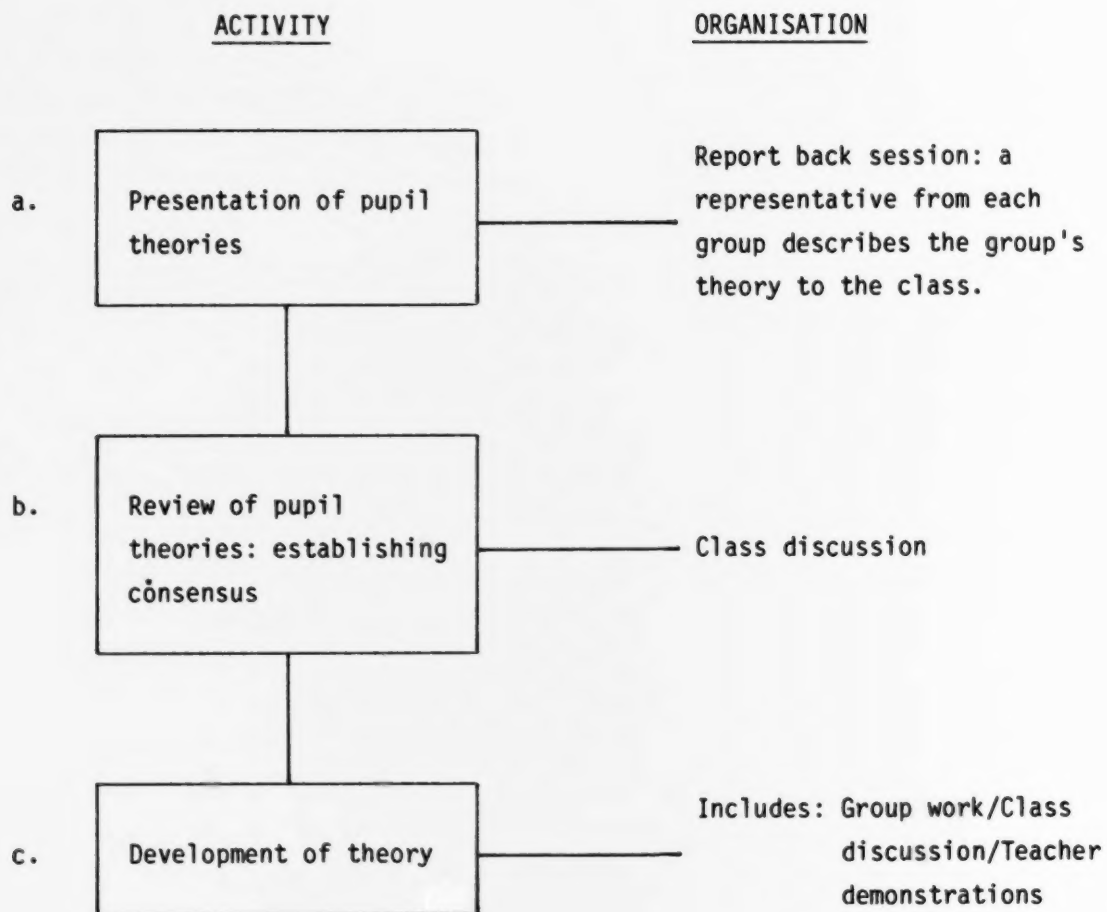
"Relieved that the groups were able to produce a theory without too much prompting. Quite surprised at the coherence of ideas (at least superficially - asking probing questions did reveal some weaknesses)."

PART E:
**REVIEW, REFLECTION AND MOVEMENT TOWARDS
ACCEPTED THEORY**

1. Intentions and underlying thinking

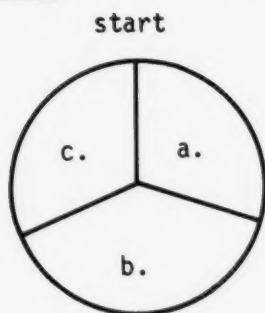
Each group is now given the opportunity to present its theory to the class. At this stage there is bound to be a 'gap' between the various ideas put forward by pupils and the accepted scientific version of the Particulate Theory of Matter. It would, however, be inappropriate for the teacher simply to provide the 'correct answers'. The teacher should assess the nature and extent of the differences between pupils' ideas and currently held scientific view, and then introduce further activities which encourage pupils to move their thinking towards the accepted theory.

2. Action plan



TIMING

Total time for the section = 2 double lessons (2 x 80 minutes)



lesson 2 lesson 1

- a. = Presentation of pupil theories
- b. = Review and establishing a consensus
- c. = Development of theory

3. The activities

a. Presentation of pupil theories

(i) Purpose

In the first part of this lesson, the posters are displayed and pupils are given the opportunity to 'report back', presenting their theories to the rest of the class. They should be encouraged to reflect carefully upon the ideas which are introduced by other groups and to consider how these ideas differ from their own.

(ii) Organisation

In order to encourage maximum pupil participation in this report back session it is important that careful consideration is given to the way in which the class is arranged. In particular, it has been found useful to focus the attention of pupils away from the teacher. The reports from each group should be directed towards the whole class, not just at the teacher. Strategies which have proved useful include:

- rearranging furniture if possible e.g. display all posters on a side wall and move chairs/tables around
- if the classroom has fixed tables, turn the class round! Display posters on the back wall! Don't work from the teacher's desk
- The teacher should sit amongst the pupils rather than stand or sit in front of them. Pupils who are reporting back should stand in front of the class, as close to their posters as possible.

Two possible classroom arrangements are shown in figure 4.

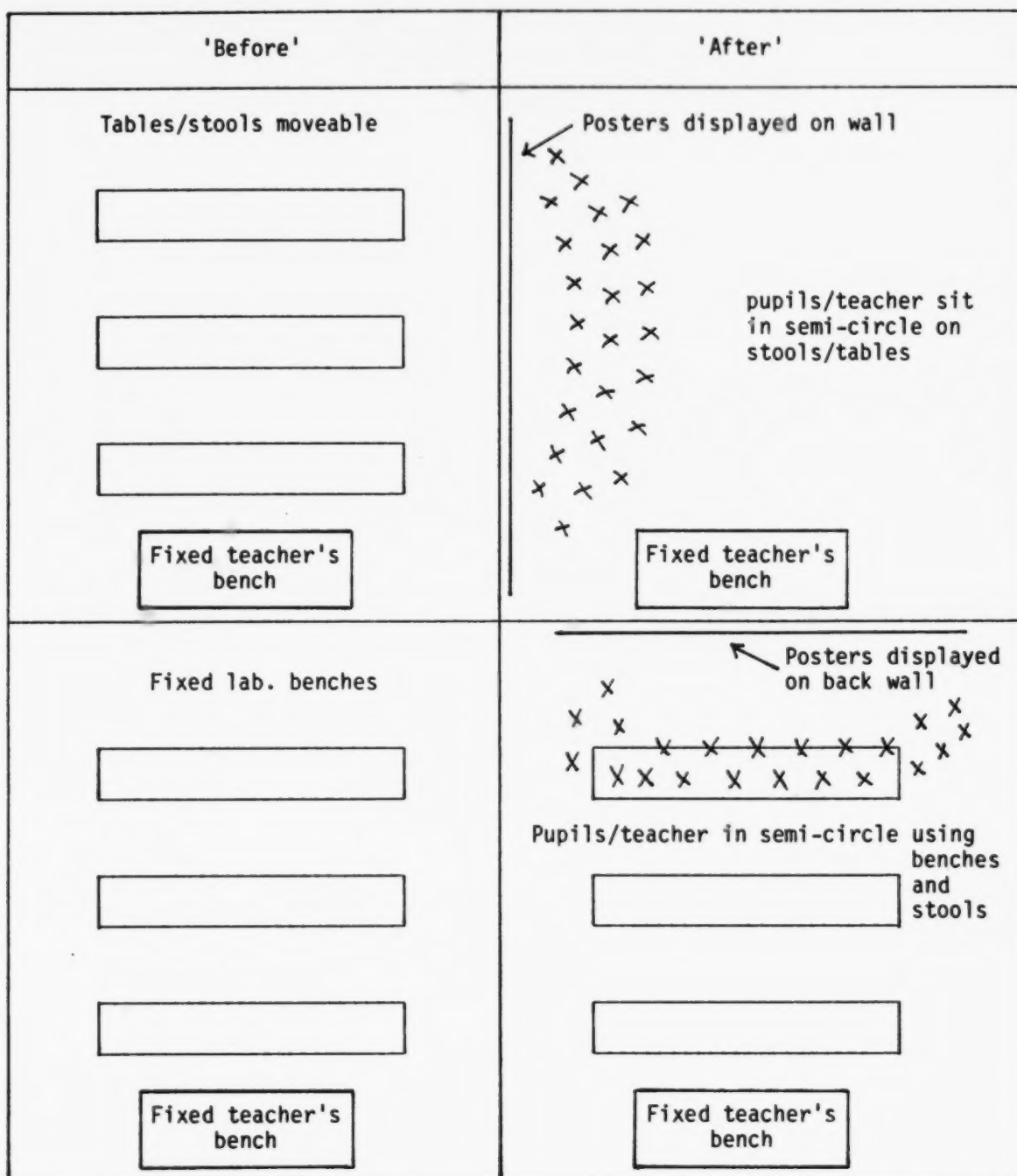


Figure 4. Classroom arrangements for report back sessions.

With a little imagination, a report back session can be held in a classroom of any shape/size. As a temporary measure, posters can be displayed on windows, blackboards, the front of cupboards or even held up by two group members while a third gives the report.

(iii) Managing the report back

The following points may be of help:

- each group should be asked to report back for no more than three or four minutes. Speakers might be asked to:
"go through your group's ideas as shown on the poster and highlight what you consider to be the important points"
- some pupils may find reporting back difficult. The teacher should help and encourage them, perhaps by asking simple questions
- each speaker should be thanked for their contribution by the teacher
- when each speaker has finished it may be worth asking if any other members of the group would like to add anything
- an opportunity should be provided for members of the class to briefly question each speaker at the end of his/her report back
- when all presentations have been made, a further five minutes might be allowed for general questions and discussion
- at this stage, teacher questions should be limited to asking for clarification and more information about ideas presented on posters
- as each group reports on its work, the teacher should note (either mentally or on paper) areas of general agreement within the class, points over which there is obvious disagreement between groups, points of general interest etc., in preparation for the next activity
- the timing of the report back will depend on the number of groups: for a class of 30 it may take as long as 40 minutes.

b. Review of pupil theories: establishing a consensus

(i) Purpose

The review develops from the report back into a more wide ranging discussion. The teacher takes a more active role, encouraging pupils to sift through the range of theories presented, and to critically evaluate each others' ideas. The review is one of the less predictable parts of the teaching scheme. It is difficult to be prescriptive about how this lesson should be run, as each class, with its own set of theories, will respond differently. From the group's experience with the scheme it does seem, however, that there are ideas which tend to be raised time after time by pupils of all ability ranges. It is therefore possible to suggest in advance some of the strategies which teachers may find useful when confronted with these ideas.

(ii) Organisation and management

The review session is, in organisational terms, simply an extension of the report back, and the arrangement of the class should remain as before. It is difficult to make firm recommendations about the timing of the discussion. It is not unrealistic to allocate a double lesson for both the report back and the review session. The teacher should, however, be flexible, bringing discussion to a close or allowing it to continue depending on the level of involvement within the class.

Note: In the unlikely event that there has been no mention of atoms, bits, particles, molecules by any group at this stage, the teacher may wish to introduce the idea him/herself, as another alternative way of looking at the problem (not however at this stage as the 'right' answer).

It is likely that within any class a variety of ideas will emerge from the posters and discussion during the report back. These might include:

- aspects of particulate theory correctly applied
- alternative ideas about particulate theory
- macroscopic ideas
- omissions - aspects of particulate theory which have not been considered.

Taking ideas from posters which have been produced by pupils using the scheme, examples (from each of the categories described above) are now presented.

Aspects of particulate theory - correctly applied

- e.g. - the use of particles (as opposed to some continuous model)
- the particles correctly oriented in space (the students having drawn upon the evidence of compression and shape in the pattern of properties)
 - the extremely small size of the particles

e.g. see poster on page 106

Particulate theory incorrectly applied

- e.g. - particle packing incorrectly displayed
- air shown between the particles
 - shape of particles variable

e.g. see poster on page 108

Macroscopic theory

Which may consist of little more than a re-write of the patterns ideas collected thus far.

e.g. see poster on page 105

Aspects of particulate theory which have been left out

- e.g. - no mention of the motion of particles
- no consideration of bonding/forces

e.g. see poster on page 107

The teacher should start by focussing the discussion on aspects of correctly applied particle theory which most groups have mentioned on their posters.

- Do most of the class agree with the idea of particles?
- What about the packing/spatial arrangement of the particles? Can the class reach a consensus view on this?

Experience suggests that many pupils are happy with the idea that particles (they may call them atoms, molecules or 'bits') are a useful way of explaining some aspects of the nature and behaviour of matter. They also seem to feel comfortable with a view of particle spacing which has particles in liquids and solids very close together and particles in gases much more widely separated (the syringe activity from the elicitation section is frequently cited by pupils as evidence for this idea). Some pupils justify the more random packing of particles in liquids (as opposed to regular packing in solids) with reference to the way in which liquids can flow.

More contentious issues include:

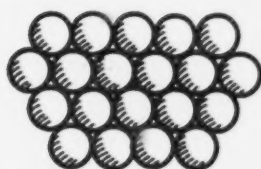
- what is between particles (particularly in a gas)?
- does anything hold the particles together, or do they stay together in solids simply because they are tightly packed and "can't get out"?

It is rare for pupils to mention the issue of motion of particles, even though they have been observing a copper sulphate/water diffusion experiment throughout the lessons.

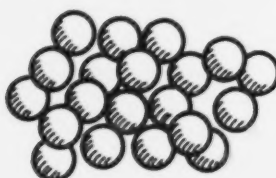
At this stage, the teacher might summarise the consensus theory of the class as:

- all substances contain particles/atoms/molecules/bits (using the term which pupils felt most comfortable with)

- the particles are arranged as follows:



Solid



Liquid



Gas

Next, the teacher will actively intervene, in order to develop this "consensus theory".

c. Development of theory

(i) Purpose

In this section, the teacher uses various means to encourage pupils to move their thinking towards the currently accepted theory of the particulate nature of matter.

Issues which need to be addressed will of course vary from class to class, but it is likely that they will include at least some of those mentioned above e.g:

- what is in between particles?
- what (if anything) holds the particles together?
- do the particles move?

For each of these issues, the teacher should try to provide pupils with OPPORTUNITIES TO THINK THROUGH THE PROBLEMS FOR THEMSELVES before the teacher provides the correct answer.

(ii) Organisation

It is impossible to be prescriptive about what should be done at this stage, as the teacher needs to adopt a 'diagnostic' role, identifying problems and dealing with them in ways appropriate for the class.

Some examples are now provided of possible ways of approaching the problem issues.

(iii) Possible ways forward

What is in between the particles?

This question applied particularly to gases, though problems also arose when pupils described water molecules which floated in liquid water etc. For many pupils this is a philosophical issue. The teacher cannot prove to the class that there is nothing between gas particles.

One way forward is to use a worksheet (such as Worksheet R1 which can be found on page 135).

Pupils are asked to discuss this idea in groups and say whether they agree with it or not. Responses from groups included the following:

Her diagram is correct except the gaps in between the air molecules are filled with nothing.

"Her diagram is correct except the gaps in between the air molecules are filled with nothing."

We disagree with Rosalind's idea about air particles in air. We would cross out the label 'Air' and label it nothing.

The air itself is made up of gas particles.

"We disagree with Rosalind's idea about air particles in air. We would cross out the label 'Air' and label it nothing. The air itself is made up of gas particles."

We think that Rosalind's diagram is Good.

We agree with Rosalind's theory of air

We think that Rosalind's diagrams describes air very well.

And the labels are very clear.

"We think that Rosalind's diagram is GOOD.

We agree with Rosalind's theory of air.

We think that Rosalind's diagram describes air very well.

And the labels are very clear."

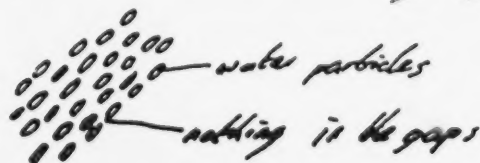
The responses of various groups to such a question may be used as the basis for further class discussion.

Worksheet R2 (page 136) has been used to promote discussion about 'air' in water.

Another way forward might be to ask pupils to describe what pure water is like inside. Some responses to this question are shown below.

Pure Water

Inside it's made up of lots of particles.
These are microscopic. They are very
tiny gaps inbetween. There isn't anything in the gaps

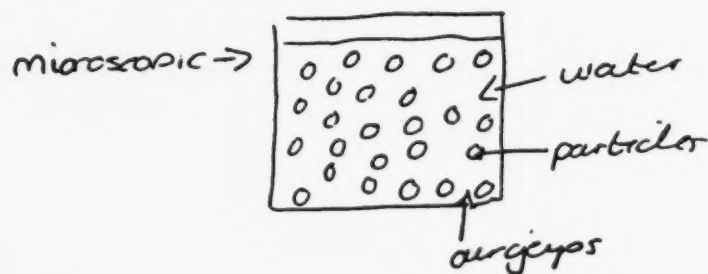


"Pure Water. Inside it's made up of lot's of particles. These are microscopic. They are very tiny gaps inbetween. There isn't anything in the gaps."

Sharon

Pure Water

Inside a glass of pure water (microscopic) are tiny particles and they are moving about all over the place. These particles are mixed in the water with air so there is air gaps between each particle.



"Pure Water. Inside a glass of pure water (microscopic) are tiny particles and they are moving about all over the place. These particles are mixed in the water with air so there is air gaps between each particle."

Julie

What holds the particles together?

Many pupils felt that particles in solids held together simply because they were packed closely. Stacking polystyrene balls in pyramids and knocking them down is one way to challenge this idea. Again, worksheets could be used as a basis for group and/or class discussion (see R3, page 137). The extent to which this is developed will depend on the ability and interest of the class. It may be enough, at this stage, for the class to agree that something holds the particles together more in solids.

Movement of particles in solids, liquids and gases.

The liquid (copper sulphate/water) and diffusion experiment can be referred to at this point. Possible gaseous diffusion demonstrations which could also be used might include:

ammonia/hydrogen chloride (for instructions see page 139)

bromine in air

bromine in a vacuum

Teachers may already have their own 'favourite' diffusion demonstrations, which it would be appropriate to use at this stage.

Discussion worksheets (e.g. for ammonia/hydrogen chloride, R4) might also be used in conjunction with the demonstrations. Such demonstrations allow the teacher to elicit from pupils the idea that particles appear to move of their own accord:

- quite freely in gases
- to a much more limited extent in liquids
- hardly at all in solids.

The use of bromine in air/bromine in a vacuum demonstrations encourages pupils to reflect on the speed at which gas particles move when nothing (such as air particles) is in their way.

An example of a written response to these demonstrations (put together by a group of pupils) is shown below.

1
with air

The bromine particules are obstructed by the air particules which slows down the process of expansion of the bromine particules.

2
without air (vacuum)

without the air the bromine have nothing to obstruct it so it proceeds to move very quickly to the top.

"with air

The bromine particules are obstructed by the air particules which slows down the process of expansion of the bromine particules.

without air (vacuum)

Without the air the bromine have nothing to obstruct it so it proceeds to move very quickly to the top."

Chris, Tracy, Janine and Sean

Teachers may wish to introduce a Nuffield type kinetic model at this stage (pupils may, however, find such models confusing).

The size of particles.

The issue of particle size creates conceptual difficulties similar to those surrounding the question, "what is in between the particles?". A difficulty in comprehending the size of particles can also lead to a misunderstanding of the size of the 'empty spaces' between them. Pupils have expressed concern that "if the particles are all spread out in gases, how come when we breathe in we always get some air? Why don't we breathe in the gaps and feel out of breath?" Without an appreciation of the scale of particles, pupils cannot understand that the gaps between them are also very tiny. It is questionable whether the 'oil drop' type of experiment actually helps pupils to appreciate the size of particles. Indeed, many 13 year olds find the mathematics involved incomprehensible, without having to struggle with the ideas behind the exercise as well. Perhaps as teachers we can do no more than suggest that pupils reflect on the idea that scientists think that "there are about 50 million million million particles in a thimbleful of air, so just try to imagine how tiny the gaps in between all those particles must be". It is an issue which pupils will have to think through for themselves.

Change of state

With a more able group, or if time is available, teachers may wish to develop the class theory further, to include a consideration of change of state. This could be pursued through class practical work on heating/cooling curves.

By involving the class in some of the activities described above the consensus theory can be further developed. The nature and extent of this theory will vary from class to class, but it should include most or all of the following points:

- all matter is made of particles (atoms/molecules/bits)
- the spatial arrangement of the particles is different for solids, liquids and gases

- a vacuum (nothing) exists between the particles
- particles have intrinsic motion. They move 'of their own accord'
- particles move differently in solids, liquids and gases
- the particles and the gaps between them are very small
- something holds the particles together tightly on solids, less tightly in liquids and seemingly not at all in gases.

Some of the worksheets (R1-R4, pages 135 to 138) could be used as homework exercises rather than as a basis for class discussion.

4. Reflections on Part E: Review, reflection and movement towards accepted theory

a. General comments

Alternative ideas which the teacher will need to address in this section may include:

- air in the space between particles (in solids, liquids and gases)
- various alternative ideas about bonding/forces between particles (including the idea that bonding is not necessary)
- size/scale issues and also perhaps the issue of shape
- issues related to movement of particles.

There is not one way forward at this stage. The teacher must first identify the problems which his/her particular class have raised and select strategies which seem appropriate to that class. What are presented above are some of the strategies which worked for project teachers in their classrooms with their pupils.

In choosing strategies the teacher should be guided by the principle that pupils need the opportunity to think some of these problems through for themselves before being 'told' the answer.

The Review/Development section can be very demanding for both pupils and teacher, but with some thought and planning the lessons can be the most exciting and enjoyable of the scheme.

b. Comments from pupils

in today's lesson we were discussing
the posters we did on Tuesday
we went through each on in turn
4 out of the six groups
came up the particles idea we
came up with a problem about
what was inbetween the particles
we still have not come up with the answer.

"In today's lesson we were discussing the posters we did on Tuesday we went through each on in turn 4 out of the six groups came up the particles idea we came up with a problem about what was inbetween the particles we still have not come up with the answer."

We started
the lesson by finishing off our posters which
was interesting again. When all the posters were
finished we put them up and somebody from
each group read them out. I agreed wholeheartedly
with most of the groups conclusion that the
space between molecules (or bits) mattered, as
to whether the substance behaved in a
different way from the others. I didn't agree with Judith's
(again) because I don't think that molecules weigh
different amounts, just that they are arranged
differently in the solid, liquid or gas.

"We started the lesson by finishing off our posters which was interesting again. When all the posters were finished we put them up and somebody from each group read them out. I agreed wholeheartedly with most of the groups conclusion that the space between molecules (or bits) mattered, as to whether the substance behaved in a different way from the others. I didn't agree with Judith's (again) because I don't think that molecules weigh different amounts, just that they are arranged differently in the solid, liquid or gas."

Graham

*In my mind we still didn't
say whether there ~~is~~ or aren't any particles
in the three (subjects) liquids, solids gases. My
Mind is still pondering on it know as I write
my diary. Sir Somebody must know the answers
to the Question because there has to be some
kind of answer to every Question BUT it is
finding the right one I find the problem.
On the hole it was a very Interesting lesson.
Its not very often in class discussion when
somebody says something and nobody laughs
at what that person has said.*

"In my mind we still didn't say whether there are or aren't any particles in the three (subjects) liquids, solids gases. My mind is still pondering on it know as I write my diary. Sir somebody must know the answers to the question because there has to be some kind of answer to every question BUT it is finding the right one I find the problem. On the hole it was a very Interesting lesson. Its not very often in class discussion when somebody says something and nobody laughs at what that person has said."

Heather

c. Comments from teachers

(i) Presentation and review of pupil theories

"This lesson was a cracker! I did not want to dominate the proceedings ... but it quickly became apparent that teacher input was needed to help focus upon the issues. The question of what exists between air atoms took us right away from particle theory ... and back again."

"By the end of the lesson I felt as if I had ranted/raved/told jokes/implored for participation/demanded concentration/indulged in self mockery - and by the end of the lesson alternative theories were MANIFOLD! what happens next??"

"Nearly all the class seemed to be properly involved and the discussion seemed to flow well without any input of ideas from me."

(ii) Development of theory

"The lesson felt to go reasonably well. The input was largely from the teacher and there was a lot of it. Hopefully the variation in thoughts/demonstrations helped to sustain interest."

5. Practical details

This section contains the following:

- worksheets

R1 AIR TODAY GONE TOMORROW

Considers the issue of what is between the particles in a gas.

R2 POOR FISHY

Considers whether there is air between the particles in water.

R3 WHAT HOLDS THE PARTICLES TOGETHER?

Considers bonding in solids, liquids and gases.

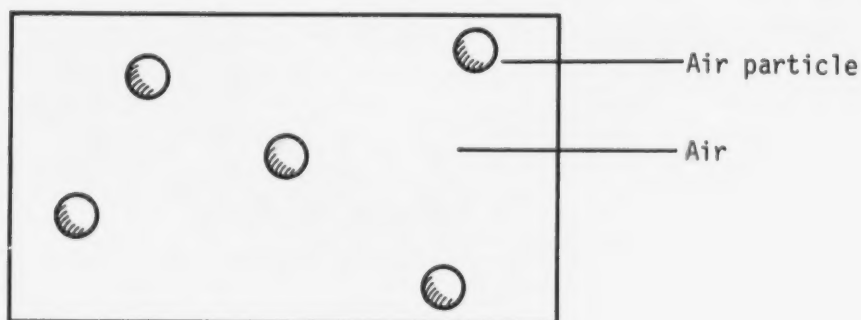
R4 CLOUDS

A question on the ammonia/hydrogen chloride diffusion demonstration.

These worksheets could be used either as a focus for group discussion or as individual homework questions.

- instructions for a gaseous diffusion demonstration.

Rosalind's science teacher asked her to draw out a PARTICLES diagram of air - the air in the room. This is what Rosalind drew:



1. Do you think that Rosalind's idea of AIR is good or bad?
2. Do you agree or disagree with her?

Write out what you think of Rosalind's diagram and labels.

.....

.....

.....

.....

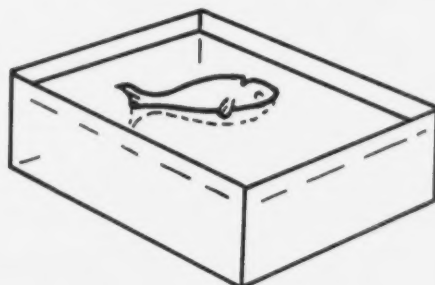
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POOR FISHY

R2

Albert had a fish whose name was Basil. Albert was very fond of Basil. Albert's science teacher told him that distilled water is absolutely PURE (nothing extra in the water at all). Albert thought that little Basil would like PURE water, so he put Basil in a tank filled with distilled water, and sealed the top.



Poor old Basil (R.I.P.)

Basil had plenty of food,
but he DIED.

Poor old Basil.

A. Why did Basil die? (He was always such a healthy little fish.)

.....
.....
.....

B. Draw a PARTICLES diagram of pure
DISTILLED WATER (just show a water
particle as a ○ as normal).

DISTILLED WATER



C. Draw a PARTICLES diagram of
ordinary TAP WATER (the kind Basil
used to like). Label the particles
in this diagram.

TAP WATER



WHAT HOLDS PARTICLES TOGETHER

R3

- * Simon tries to run through a brick wall and fails.
- * Joanne runs through the water at the swimming pool (chasing a friend) and falls over.
- * Richard cuts through the air to sprint 100 metres in 8 seconds .. a new world record.

1. WHAT holds the PARTICLES together:

- TIGHTLY in solids (walls)?



- WEAKLY in liquids (water)?



- NOT AT ALL in gases?



2. WHY should there be this DIFFERENCE?

.....

.....

.....

.....

.....

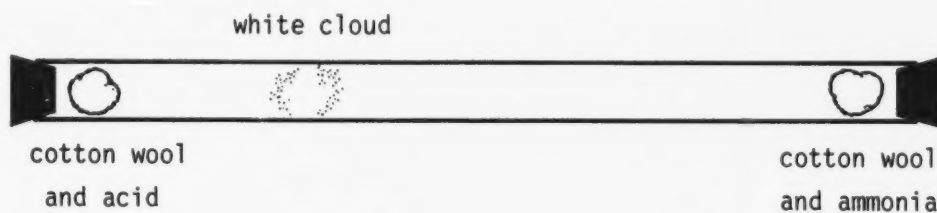
CLOUDS

R4

When ammonia gas mixes with the gas from hydrochloric acid (hydrogen chloride gas) a WHITE CLOUD is formed.

One piece of cotton wool was dipped in ammonia and another piece was dipped in the acid.

The pieces of cotton wool were placed at the ends of a long, sealed, air-filled glass tube:



A white cloud was formed after a few minutes!!

In the box below explain why the cloud forms.

Diffusion demonstration

CLOUDS

Requirements:

A glass tube between half to one metre long

Two bungs (rubber) to fit tube

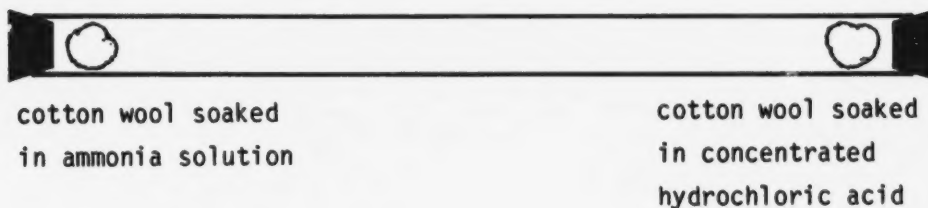
Tweezers

Two small beakers or evaporating dishes

Cotton wool

Concentrated (.880) ammonia solution

Concentrated hydrochloric acid



It may be worth first showing pupils that a white cloud is formed when ammonia and hydrochloric acid are brought together (bring the stoppers from the acid and ammonia bottles together without letting them touch).

Pour some hydrochloric acid into one small beaker and ammonia solution into another. Using tweezers, soak a wad of cotton wool in ammonia and then place it in one end of the tube. Replace the bung. Repeat with hydrochloric acid, placing this wad of cotton wool in the other end of the tube.

It will take some minutes for a white cloud to form.

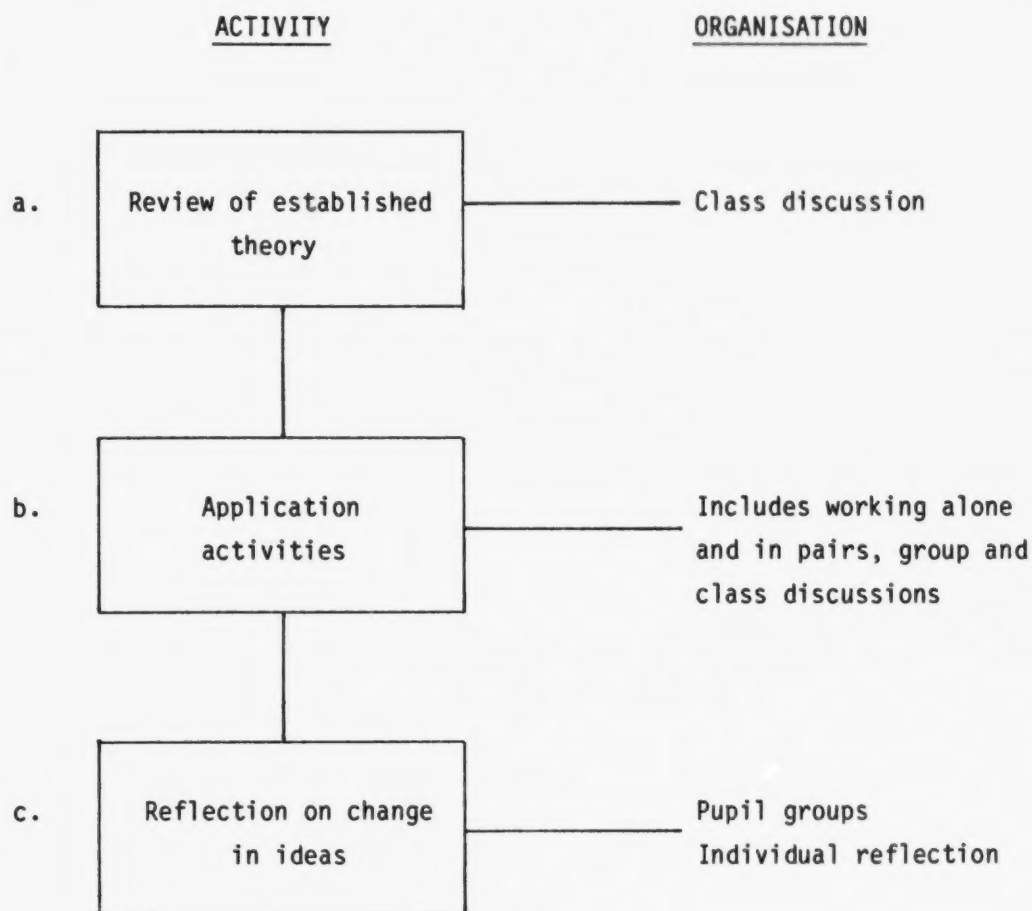
PART F:
APPLICATION OF ACCEPTED THEORY

1. Intentions and underlying thinking

Pupils are provided with opportunities to apply their newly won theory in both familiar and novel situations. It is hoped that as well as using the application section to test pupils' understanding, the teacher might also use some of the more novel situations to further extend the theory.

Finally, pupils should be explicitly encouraged to reflect on how much their ideas have changed over the last few weeks.

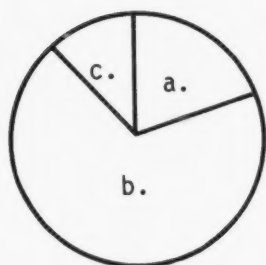
2. Action plan



TIMING

start

Total time for the section = approximately 1 double lesson
(1 x 80 minutes)



- a. = Review
- b. = Various application activities
- c. = Reflection on change in ideas

If more time is available, two double lessons could be spent on this section.

3. The activities

a. Review of established theory

(i) Purpose

The teacher should review the 'final' version of the theory with the class, and produce with them some tangible record of it (either as a 'handout' such as that shown on pages 150 and 151, or as notes which pupils can record in their books). It would also be appropriate at this stage to tell pupils that this theory is used by scientists and is known as 'The Particulate Theory of Matter'.

(ii) Organisation

There are various ways of organising this review. Perhaps the simplest way of running it is for the teacher to prepare a handout and talk through it with the class. If more time is available, perhaps groups of pupils could be asked to prepare handouts, and these could be considered by the whole class. The teacher could then summarise ideas from the handouts so that pupils could make a record of them.

The time required for the review will depend on the way in which it is organised. Talking through a handout with the class may only take 15 or 20 minutes. Other types of review will require longer.

b. Application activities

(i) Purpose

The application activities are designed to:

- investigate pupils' understanding of the theory in familiar situations
- investigate understanding in slightly novel situations
- allow the teacher to identify problems in understanding, and to take appropriate remedial action
- allow further development of the theory.

(ii) Organisation

Application activities might include the following:

- a circus of practical activities
- diagnostic questions for pupils to respond to individually
- imaginative writing exercises
- 'comprehension' exercises
- a more formal assessment, of the sort often used as an end of unit test.

Suggestions for activities are given in Section 5. Practical activities (page 149).

It is suggested that the circus of practical activities forms the basis of this section and that other activities are selected if time allows and if the teacher feels that they are appropriate to the needs of the class.

One way to organise the circus might be as follows:

Class size = 24		
Activity	Property	Number of sets
Blocks-2	Density	1
Crystals	Packing/bonding	2
Syringes-2	Compressibility/packing	2
Melt	Change of state	2
Purple rain	Diffusion	2
Tight fit	Expansion	1
Burnt fingers	Conduction	2

There are many other activities which come to mind which would be appropriate for inclusion in such a circus. We would encourage teachers not to feel constrained by the activities detailed in this scheme but to develop practical activities appropriate to their own students and to the resources available in their schools.

The circus of practical activities should be organised in a similar way to that in the initial section of the scheme (Elicitation of pupil ideas). The teacher may, however, prefer pupils to work individually rather than in pairs.

c. Reflection on change in ideas

(i) Purpose

To encourage pupils to look back over the series of lessons and consider how their ideas have changed.

Some pupils might reflect on their learning without being prompted. Most, however, need encouragement to engage in this sort of activity. They are too often used to regarding science lessons as separate isolated incidents within the school week, making little connection between one lesson and the next.

(ii) Organisation

- Encourage pupils to reflect individually on what they have learned and how their ideas have changed.
- Ask pupils to write a diary entry or homework exercise on what they think they have learned.
- Allow groups 15 minutes at the end of the last lesson to review the posters which they designed during the elicitation section, and if they wish, to make changes/additions to them.

4. Reflections on Part F: Application of accepted theory

a. General comments

The teacher should, during the 'Application' section, be sensitive to the response of the class. There is little point in contriving to struggle with the detail of the theory if the class seem to have 'had enough'.

If these lessons are regarded (as they should be) as an introduction to the Particulate Theory of Matter, then further opportunities to apply and develop the theory should be built into future science courses. Further, if pupils have been actively involved in the lessons, it is hoped that they will continue to use some of their new ideas about matter, where appropriate.

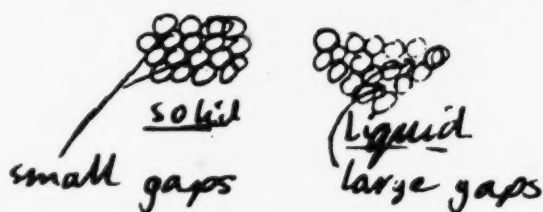
b. Comments from pupils

The next experiment was one called Hot wax. We got a rod of wax and heated it. It began to burn and fell away. Maybe it fell away because the friction caused by the vibration broke the links between the molecules which meant they were no longer linked. Therefore they fell away.

"The next experiment was one called Hot wax. We got a rod of wax and heated it. It began to burn and fell away. Maybe it fell away because the friction caused by the vibration broke the links between the molecules which meant they were no longer linked. Therefore they fell away."

Robert (melting wax activity)

After that we went back to the other experiments that we did some time ago and that included the syringe experiment and some other experiments to do with heating and melting things. I did all those experiments before, but not the one which was called, 'tight fit' one. In this experiment a ~~metal~~ metal rod which fitted into a hole, was heated and then you tried to put it back. It was too big to fit, even though it fitted in before. This probably backs up the idea of the molecules in a liquid more far apart than in a solid, but still not compressable.



"After that we went back to the other experiments that we did some time ago and that included the syringe experiment and some other experiments to do with heating and melting things. I did all those experiments before, but not the one which was called, 'tight fit' one. In this experiment a metal rod which fitted into a hole, was heated and then you tried to put it back. It was too big to fit, even though it fitted in before. This probably backs up the idea of the molecules in a liquid more far apart than in a solid, but still not compressable."

John (metal expansion activity)

Craig (C) - interview with researcher (R)
Diffusion Activities - Air Freshener and Perfume

- R .. is there any lesson in this series of lessons that really sticks in your mind as being one you really enjoyed?
- C Erm, I don't know, I think it was when we did all the first experiments and this lesson.
- R This one today as well?
- C Yeah.
- R Is that because of the experiments?
- C Yeah, and probably t'progress that we've made.
- R Are you aware ... that you've made progress? Do you know you've made progress?
- C Yeah.
- R Can you tell me a bit more about that? How you feel that you've progressed.
- C Well, before we started on this work we didn't - on the air freshener one I thought maybe because the gas was a lot lighter.
- R Mm.
- C But now we've done a bit more, it was the particles that were moving.
- R Yes. That's a - do you find that one easy to understand?
- C Yeah.
- R And you actually know you understand it better?
- C Yeah.

c. Comments from teachers

"The presentation of accepted theory - from the duplicated sheet was kept brief. The 'new idea' of regular arrangement of atoms in solids was kept brief - I felt that it would be inappropriate at this stage to pursue teacher-led class discussions. The second two sheets of the handout did not provoke any particular response, but hopefully the pupils will reflect on some of the more general points."

"The application experiments were tackled well. The pupils worked in pairs and jotted down their ideas in the back of their diary. I felt that the range of experiments on offer was reasonably stimulating - and sufficiently different from the familiarisation experiments to appear novel."

5. Practical details

A pupil handout illustrating final theory can be found on pages 150 and 151.

Application activities could be selected from the following:

- a circus of practical activities (table 7 and worksheets, pages 152 to 161)
- open-ended questions either for use as homework questions or as part of a formal assessment (the teacher may wish to design his/her own diagnostic questions) (pages 162 to 165)
- a creative writing exercise - such as:

"Imagine you are a water particle in a block of ice which has just been taken out of the freezer"

"Imagine you are a water particle in a kettle"

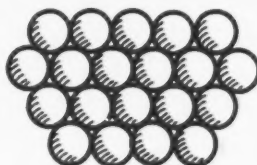
"Imagine you are an air/oxygen molecule in a bike tyre that is being pumped up"

- text related exercises e.g:

select a passage from a science textbook and ask pupils individually to rewrite it so that it would be understood by their younger brothers and sisters, or their grandparents who don't know any science

groups of pupils are given different passages from textbooks to work on. Each group has to make a short (5 minutes) presentation on the passage to the rest of the class, illustrated by posters, use of the blackboard, molecular models etc.

A PARTICLE MODEL FOR SOLIDS, LIQUIDS AND GASES

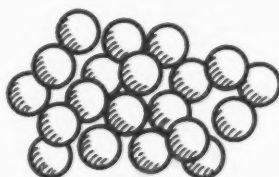


Particles are:

- i) closely packed
- ii) in regular patterns
- iii) vibrating on the spot
- iv) strongly bonded to neighbouring particles

Solids are:

- not easily compressed; heavy/light
- of fixed shape
- take a very long time to mix
- strong

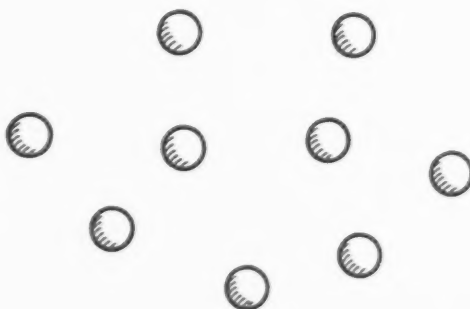


Particles are:

- i) closely packed
- ii) not arranged regularly
- iii) free to slide over each other
- iv) weakly bonded to neighbouring particles

Liquids are:

- not easily compressed; heavy/light
- of no fixed shape
- able to mix slowly
- liquid show a limited amount of strength



Particles are:

- i) widely spread out
- ii) not arranged regularly
- iii) free to move of their own accord
- iv) not bonded together

Gases are:

- easily compressed; light
- of no fixed shape
- able to mix/spread quickly
- not strong at all

A PARTICLE MODEL

The particle model of solids, liquids and gases shown on the other information sheet agrees very closely with what scientists believe lies inside solids, liquids, gases - although they often use more complicated words to describe it!

The particles are often called ATOMS or MOLECULES.

It is very difficult to imagine just how small our particles or atoms are - we have never seen them - directly or even down a microscope. Modern electron microscopes (very powerful indeed) can, however, detect them and it has been calculated that:

There are 50,000,000,000,000,000 particles in a thimbleful of air!!

When we say that the particles in a gas are 'spread out' we must remember that we are talking about microscopic particles which are really (by everyday measurements) very close to each other - the 'gaps' are certainly not very big! Gas particles also move very quickly in between collisions with each other. It has been calculated for instance that:

Air particles travel, on average, at 500 m/s!!

Particle theory can be useful because it allows us to explain the behaviour of the matter or stuff around us. Lots of seemingly unconnected phenomena (things) can be explained and understood by using one simple theory, e.g:

- | | |
|--|---|
| * a metal expands on heating | - because the particles vibrate more and take up more room. |
| * a wire snaps on loading | - because the load overcomes the bonding between neighbouring particles. |
| * the smell of perfume | - because some perfume particles escape from the bottle and mix and travel quickly through the surrounding air particles. |
| * a lump of iron cannot be squashed | - because the iron particles are packed so closely together. |
| * a cup of water boils away to produce a room full of steam. | - because water particles in steam are much more spread out than water particles in liquid water. |

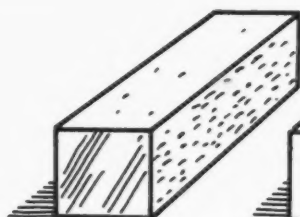
TABLE 7. APPLICATION ACTIVITIES

A8 Snap and A9 Melt repeated
from elicitation activities.

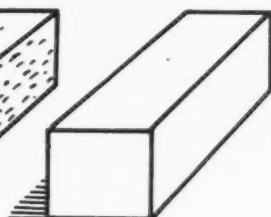
Activity Property	Blocks-2 A1	Syringes-2 A2	Perfume A3	Purple Rain A4	Crystals A5	Tight Fit A6	Burnt Fingers A7	Snap A8	Melt A9
Density	✓								
Strength/ Bonding					✓			✓	
Change of state									✓
Diffusion			✓	✓					
Compressibility/ Packing		✓			✓				
Expansion						✓			
Conduction of heat							✓		

BLOCKS - 2

A1



A



B



Balance

Inspect the two blocks.

1. How are they the same?

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2. How are they different?

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3. Explain what you have noticed in terms of PARTICLES.

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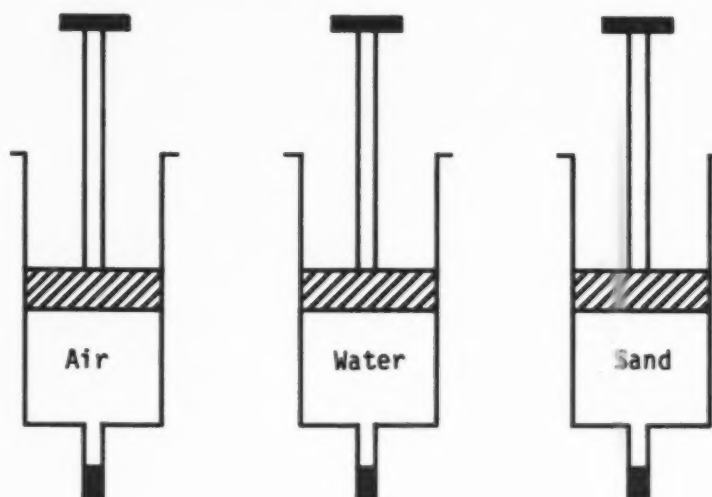
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SYRINGES – 2

A2



Press the plunger down in each syringe.

1. What do you notice?

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2. Explain what you have noticed, in terms of PARTICLES.

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Open the top of the perfume bottle.

How is it that you are now able to smell the perfume? Explain in terms of PARTICLES.

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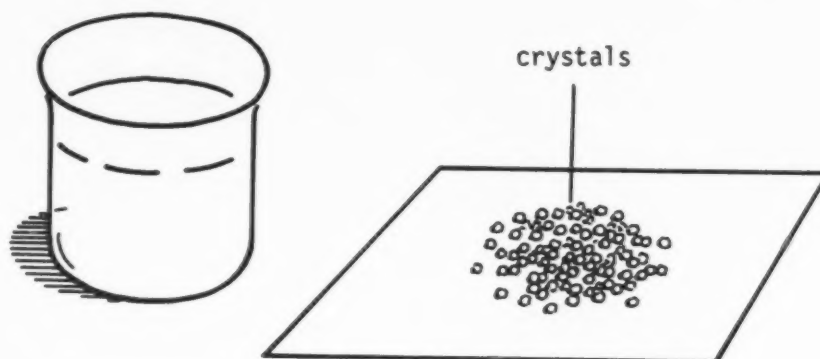
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PURPLE RAIN

A4



- * Fill the beaker with water and allow time for it to become still.
- * Select one crystal and pick it up with the tweezers.
- * Carefully drop that single crystal into the water.

1. Keep waiting for a few minutes - what do you notice?

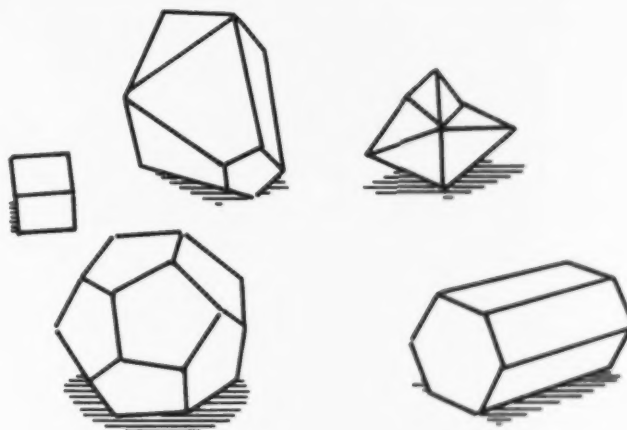
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2. Explain what you have noticed in terms of PARTICLES.

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CRYSTALS

A5



Have a good look at the collection of crystals.

Explain why the crystals are shaped like this - in terms of PARTICLES
(a sketch drawing might help).

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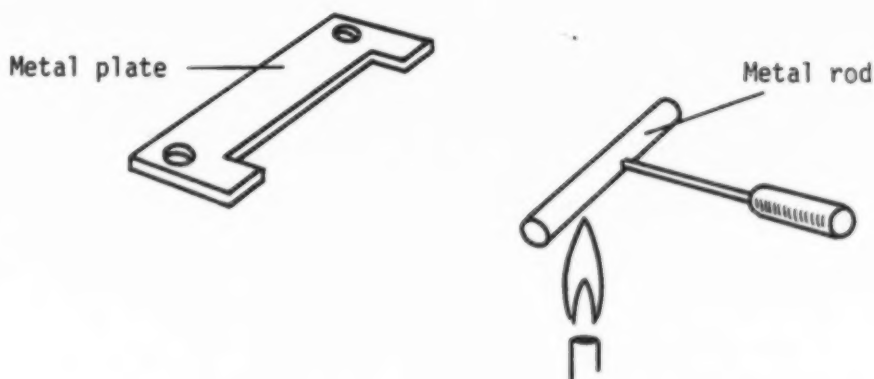
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TIGHT FIT

A6



- * Check that the end of the metal rod will fit through the hole in the plate.
- * Strongly heat the metal rod over a bunsen flame.
- * Try fitting the end of the hot metal rod into the hole.
- * Allow the rod to cool and leave it on the heat-proof mat.

Explain what you have noticed, in terms of PARTICLES.

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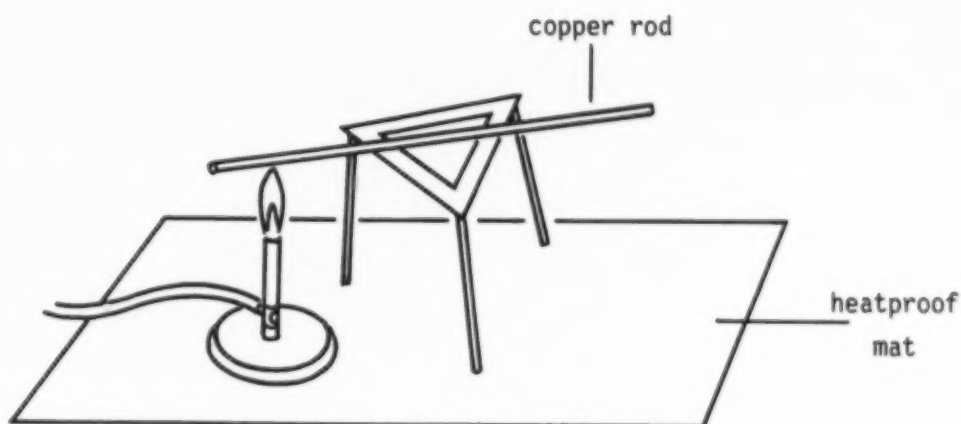
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BURNT FINGERS

A7



- * Take a copper rod from the container marked 'NEW RODS' and place it on the tripod and strongly heat one end with a bunsen flame.
- * CAREFULLY feel the other end of the rod with your fingers.

Explain what you have noticed, in terms of PARTICLES.

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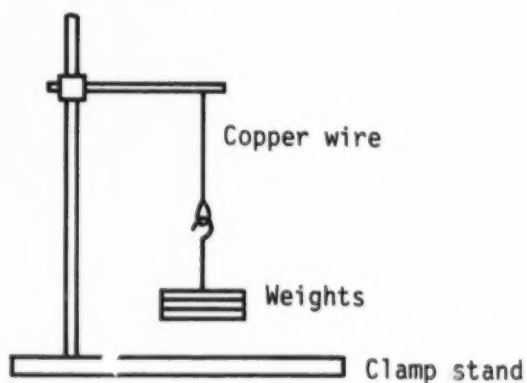
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When you have completed this activity, carefully place the rod in the container labelled 'USED RODS'.



* Set up a wire sample.

* Add 100g loads, one at a time, until the wire snaps.

1. At what load did the wire snap?

2. Explain why the wire snaps in terms of PARTICLES.

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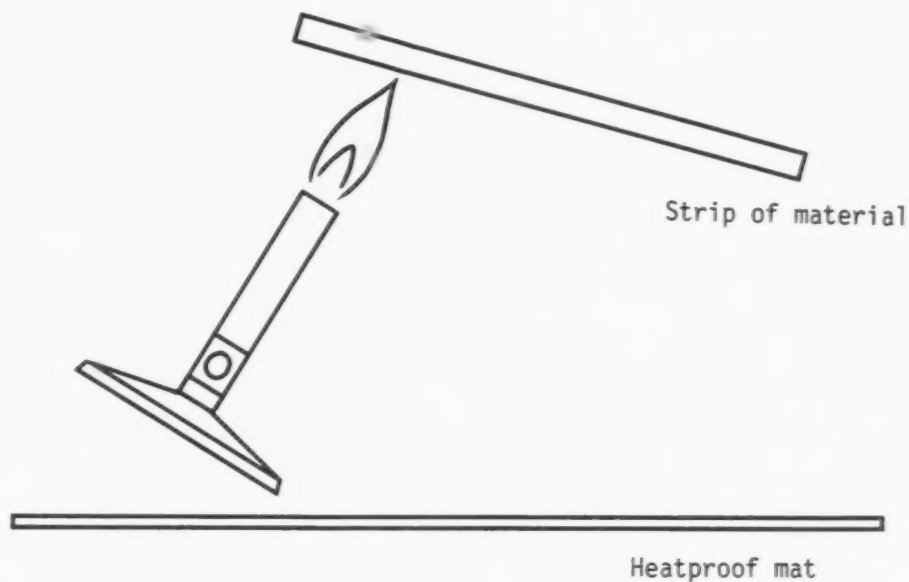
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1. What happens when you heat the strip?

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2. Explain what you have noticed - in terms of PARTICLES.

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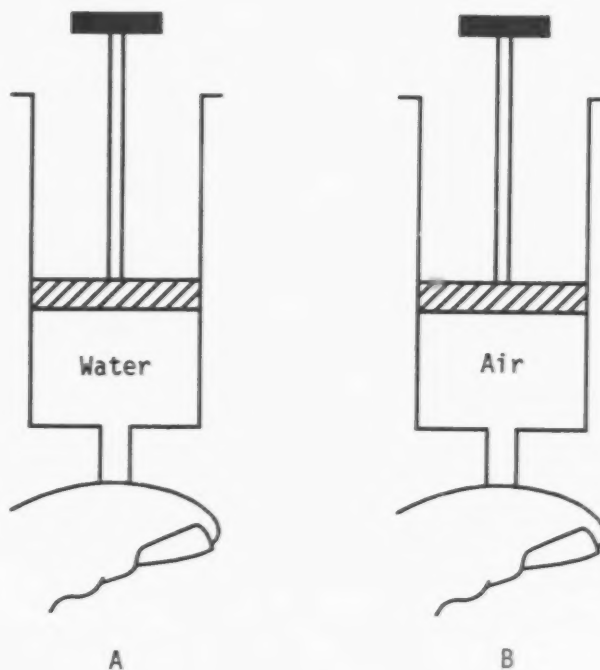
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Tracey found that if she kept her finger on the bottom end of syringe A and tried to push the plunger down, it would not move.

When she kept her finger on the end of syringe B and pushed the plunger down, the plunger moved down quite a lot.

How is it that the water was not compressed (squashed) but the air was?

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PARTICLES

Q2

After many experiments, scientists now think that everything is made up of microscopic particles called atoms and molecules. Use this idea to help you answer this question.

Make a drawing in the box to show how you think the particles are arranged and spaced in a SOLID.

Say what you think the particles are doing.

.....
.....
.....

Make a drawing in the box to show how you think the particles are arranged and spaced in a LIQUID.

Say what you think the particles are doing.

.....
.....
.....

Make a drawing in the box to show how you think the particles are arranged and spaced in a GAS.

Say what you think the particles are doing.

.....
.....
.....

What is between the air particles?

.....

SOLIDS LIQUIDS GASES

Q3

* For each of the descriptions listed below, place a S (SOLID) or L (LIQUID) or G (GAS) in the box provided. The first one has already been completed.

1. It keeps its own shape when placed in a container

S

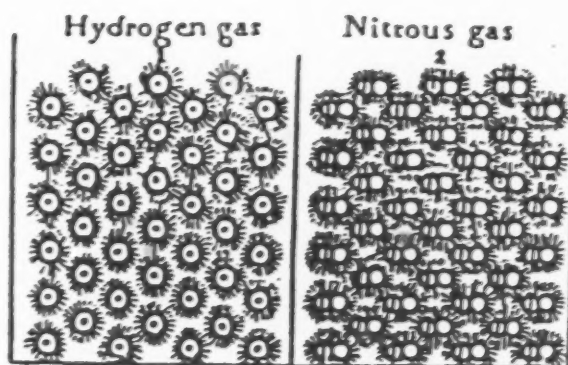
2. It takes the shape of the part of the container which it is put into.

3. It spreads out to fill its container.

4. It changes its shape when its container is tilted.

5. It can be easily compressed.

6. The top surface is horizontal.



- * John Dalton was a very famous scientist. Look at his drawings of the structure of gases - he drew them in 1810.
- * Look, in particular, at the HYDROGEN GAS drawing.
Write down, in the space below, whether or not you agree with his drawing for hydrogen - EXPLAIN YOUR ANSWER.

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(Drawings taken from Dalton J. (1810) A New System of Chemical Philosophy, vol. 1, pt. 2. R. Bickerstaff, London)

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Further reading

On views of learning:

Driver, R. (1983) The Pupil as Scientist? Open University Press, Milton Keynes.

Driver, R. and Bell, B. (1986) Students' Thinking and the learning of science: A constructivist view. School Science Review, March 1986, 443-455

Driver, R. and Oldham, V. (1986) A constructivist approach to curriculum development in science. Studies in Science Education, 13, 105-122

On children's ideas:

Children's Learning in Science Project full reports: Aspects of Secondary Students' Understanding of: Particulate Nature of Matter (1984), Heat (1984), Plant Nutrition (1984), Energy (1984), Elementary Chemistry (1986). University of Leeds.

Driver, R., Guesne, E. and Tiberghien, A. (1986) Children's Ideas in Science. Open University Press, Milton Keynes.

Osborne, R. and Freyberg, P. (1985) Learning in Science. The Implications of Children's Science. Heinemann. Auckland, New Zealand.

Postscript

We hope that readers of this scheme will be inspired to try it out in their own classrooms. We would welcome feedback on the scheme from both teachers and pupils.

It was never the intention of the Particles working group that others should follow this scheme exactly, and we would encourage teachers to adapt it in ways which fit with the needs of their own pupils. In doing so, however, we would urge them to bear in mind that pupils need time to think things through for themselves and to take on board new ideas.

Again, comments from teachers, describing any modifications which they have made to the scheme, would be most welcome.

Please address your comments to:

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